The WELDING JOURNAL

APRIL 1954

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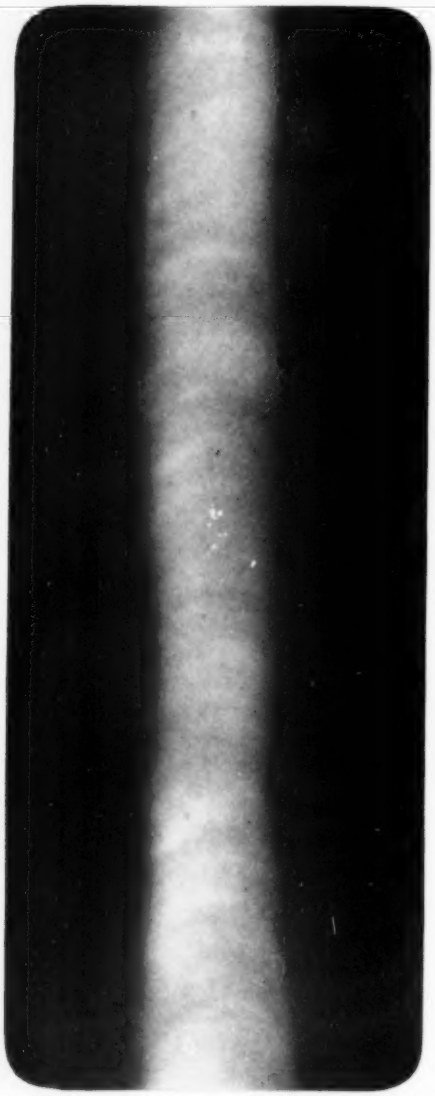

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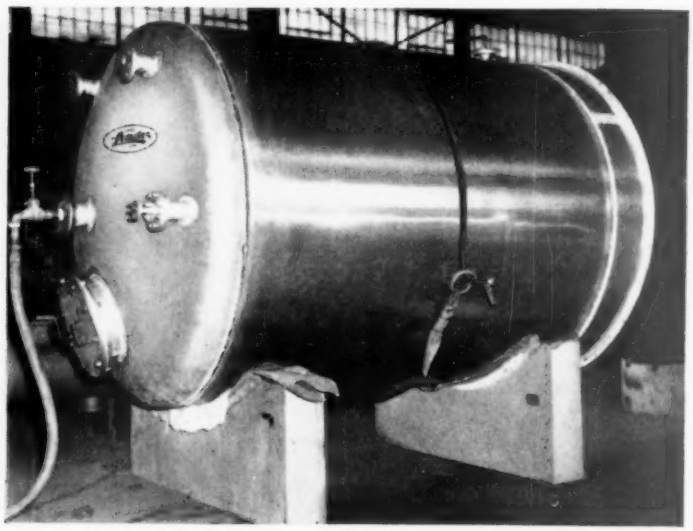

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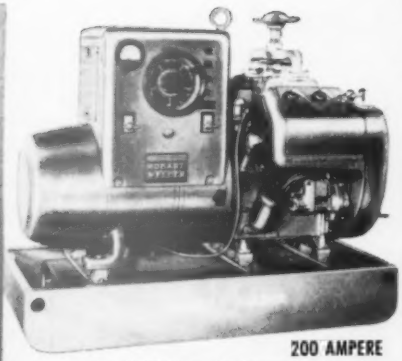

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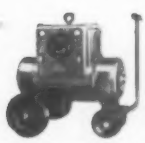
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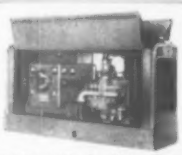
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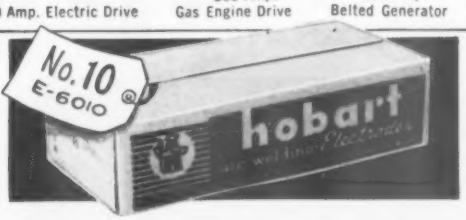

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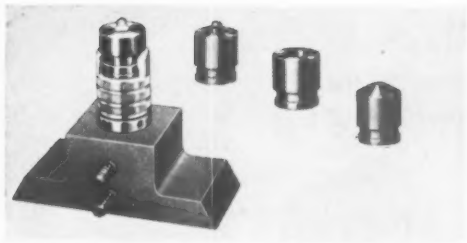

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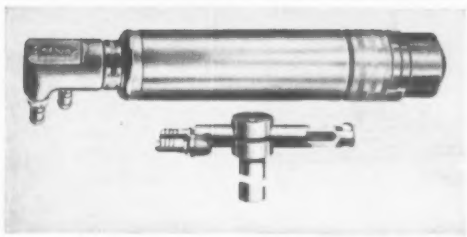

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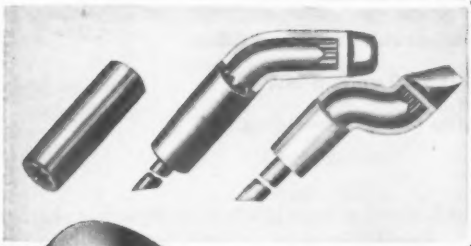

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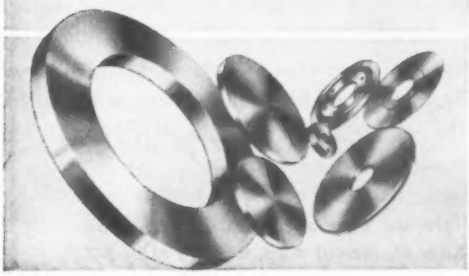

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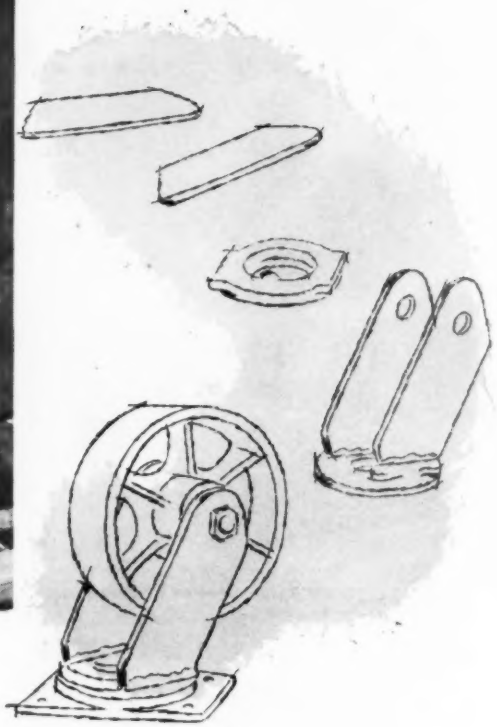

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The WELDING JOURNAL

volume 33 April 1954 number 4

Multiple Electrode Welding by "Unionmelt" Process

Nomenclature and power supply in multiple-submerged arc welding with a discussion of the advantages and applications of the several types of connections

by D. E. Knight

SINCE its introduction some 18 years ago, submerged melt welding, has proved to be an exceptionally versatile process, suitable for many different welding applications. Almost as soon as the process has been introduced, it became evident that no one rod, welding composition or power connection could be used for all applications with equally good results. Use of the process has continued to expand as research and development on the subject has provided us with new materials and equipment.

During the past few years, however, one single development has uncovered an entirely new type of operation. This is the use of more than one electrode operating simultaneously in the same welding puddle. As the possible advantages of this type of work have been demonstrated, interest has greatly increased. Several variations of technique are immediately apparent. To help avoid confusion in considering the relative advantages of the various types of multiple-electrode operation, we would like to suggest a system of nomenclature and then discuss several of these methods that are finding increased use in the welding field.

NOMENCLATURE

Three factors are required to specify any type of multiple electrode welding: number of electrodes, the type of power connection and the position of the electrodes with respect to the direction of travel. For simplicity, the power connection is further divided into three groups which are called multipower connection, parallel connection or series connection as explained in the following paragraphs.

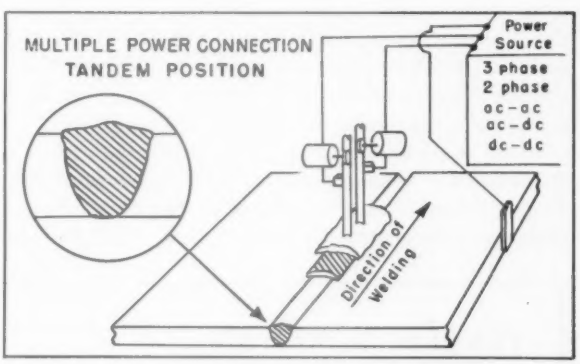

Fig. 1 Multiple power connection

In the multipower group, each electrode has its own power supply, welding head, control voltage mechanism and wire contact assembly, as shown in Fig. 1. Two- or three-phase power, or any combination of ac and dc can be supplied to the electrodes. The welding ground is attached to the workpiece and a voltage control unit governs the operation of each welding head. With multipower connections, extra high-speed welds can be made. With two- or three-phase power, magnetic effects permit better control of arc and improved operation. Note that the weld cross section area is narrow and deeply penetrated.

D. E. Knight is Development Engineer, Linde Air Products Co., Newark, N. J.

Presented at the Thirty-Fourth National Fall Meeting, AWS, held in Cleveland, Ohio, week of Oct. 19–23, 1953.

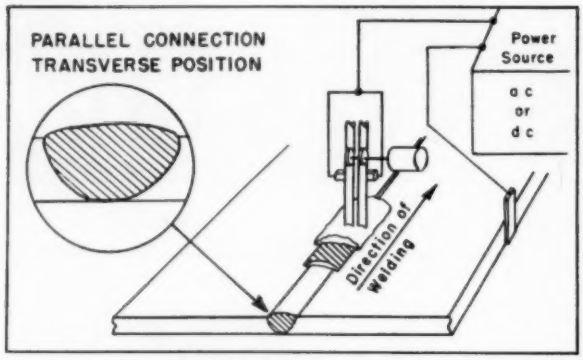

Fig. 2 Parallel power connection

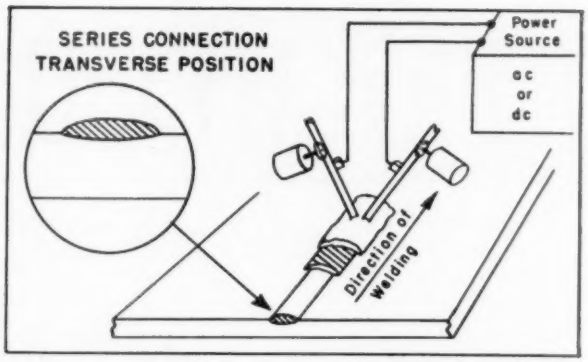

Fig. 3 Series power connection

In the parallel classification, the electrodes are connected in parallel to the power source and the welding ground is attached to the workpiece in a conventional manner as shown in Fig. 2. One voltage control unit governs the operation of a single welding head which feeds both electrodes at once. This is the only multiple electrode welding system that requires only one welding head. Only minor modifications in the wire driving the contact assembly are needed. Using this power connection, the current densities are reduced and the penetration is not so great. Frequently, this connection is used with electrodes in the transverse position to make extra wide welds for poorly fitted joints. With this position, the weld cross-sectional area is broad in comparison with the penetration.

In the series welding, two electrodes are connected in series and two welding heads are used as shown in Fig. 3. Each has its separate voltage control unit and each operates independently of its partner. One welding power supply cable is connected to one welding head. The other power cable is connected to the second welding head instead of to the workpiece as it would be in conventional welding. The welding current travels from one electrode to the other through the weld puddle and surrounding material. There is no connection between the power supply and the workpiece. When using this method, almost all of the power is used to melt the electrode and very little enters the workpiece. With the electrodes in the transverse position, a broad, shallow bead is produced that is particularly desired when applying a coat of some alloy to a base metal with very little dilution. In addition, deposition rates of the order of 25 lb per hour can be readily obtained with the series welding connection.

With any of these power connections, different effects can be produced by changing the position of the electrodes with respect to the line of weld travel. Usually, electrodes are arranged in the tandem position, shown

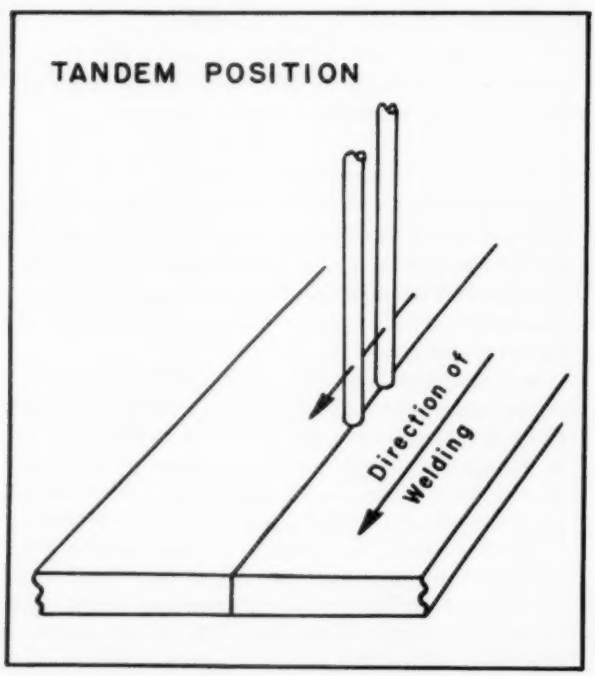

Fig. 4 Electrodes in tandem position

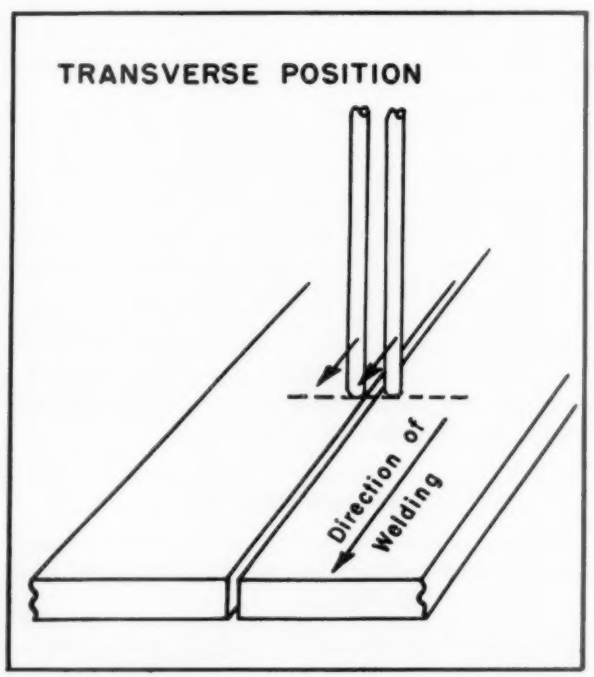

Fig. 5 Electrodes in transverse position

in Fig. 4, or the transverse position as shown in Fig. 5. With three or more electrodes, other patterns are possible.

Examples of such nomenclature are as follows:

A-c, d-c tandem welding
D-c parallel-transverse welding
A-c series-transverse welding

It is assumed that two electrodes are used unless otherwise specified. Where more than two electrodes are used, however, the number should always be included, for example: "Three-electrode parallel-transverse welding."

The advantages of each connection may be summarized as follows:

With the multiple power connection, extra-high-speed welds can be made. With two- or three-phase power, magnetic effects permit better control of arc and improved operation.

With the parallel connection, wire melting and penetrating characteristics are approximately as would be expected with the current divided between the two (or more) welding wires. Penetration is not as great as with a single wire and the same total current. Frequently, this connection is used with electrodes in the transverse position to make extra wide welds for poorly fitted joints. In series welding, almost all of the power is used to melt the electrode and little if any current flows into the workpiece. With the electrodes in the transverse position, the deposit is wide with only surface fusion of the workpiece. Thus, series transverse welding is particularly useful in achieving minimum dilution when applying alloy coatings to a base metal with very little dilution.

MULTIPLE POWER SUPPLY

In this type of welding, each electrode operates independently, having its own feed motor, voltage control, and wire contact assembly. A previous publication* described the advantages of multiple power sources and methods for using three-phase closed delta alternating current connections. When operating two electrodes in tandem, this type of power provides the maximum of flexibility in adjusting welding currents and, hence, permits better control of the welding results than can be achieved with the a-c, d-c type of power supply. However, it has the disadvantage of requiring a large investment in specialized transformer equipment.

It was also stated that the three-phase open delta connection requires only two transformers and that satisfactory welds can be made provided a reverse phase sequence is used. In practice, this is only partially true. With this connection which lacks an adjustable ground reactance it is impossible to reduce the magnitude of the ground current. To obtain satisfactory welds in some magnetic environments it is necessary to use a lower level of ground current compared to that obtained by the open delta connection. With the normal open delta connection, the phase angle between the lead and trail electrodes, at the greatest current unbalance is still close to 60 deg which is at the extreme limit of the range of phase angles (60 to 140 deg) normally found usable.

With a view toward reducing the investment in power equipment and still utilizing standard welding transformers, the Scott method of three-phase to two-phase transformation was investigated. The two-phase output of this connection and the phase angle between the lead and trail currents would be 90 deg, which is closer to the mean of the usable range of phase angles.

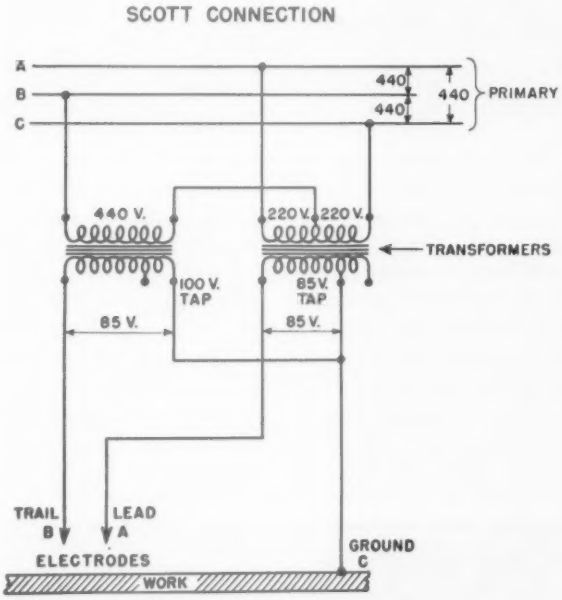

Fig. 6 Scott connection with two transformers

Standard welding transformers are of two general designs: Those in which current adjustment is obtained by an adjustable reactor in series with the welding leads; and those in which current adjustment is obtained by varying the magnetic coupling between the primary and secondary windings. Either type may be used for the Scott connection as shown in Fig. 6. The standard winding ratios are not exactly correct for the true Scott transformation, hence, the secondary open-circuit voltages are not exactly balanced. Also, there may be some unbalance in the primary supply. However, in actual practice, identical winding ratios on both main and teaser transformers can be used without affecting the welding result, even though some deviation from the theoretical 90-deg phase angle is naturally introduced with this type of connection. If more power is required, separate transformers can be connected in parallel as shown in Fig. 7.

Several advantages are usually obtained by using the Scott connection. This connection provides a source of multiple-phase a-c power for two-electrode tandem

* Clapp, E. A., and Schreiner, N. G., "Characteristics of Submerged Arc Welding with Three-Phase Power, THE WELDING JOURNAL, 31(6), 479–485 (1952).

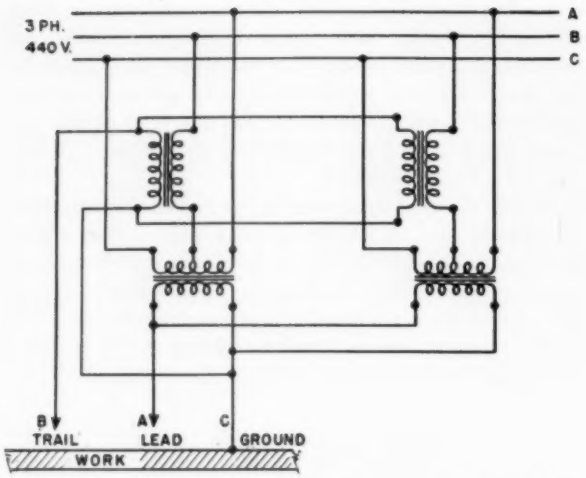

Fig. 7 Connecting transformers in parallel to obtain the Scott transformation

welding. Standard welding transformers with 220/440-v primaries can be easily connected and will produce currents in the welding lines equal to 86% of their full transformer rating. Also, the connection gives a phase angle between lead and trail electrode currents that is satisfactory for a large number of applications. Finally, this connection eliminates the ground current adjustment and thus simplifies welding operations.

However, eliminating the ground current adjustment somewhat limits the relationship between the currents of the lead and the trail electrodes for satisfactory welding. Such an adjustment may result in slower welding speed compared to what can be obtained with a full delta connection.

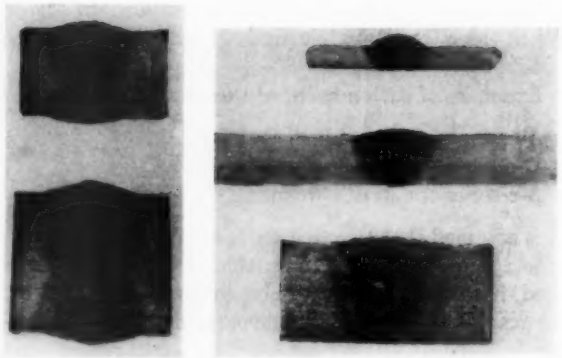

Fig. 8 Cross section of welds made with two-electrode, three-phase, tandem welding

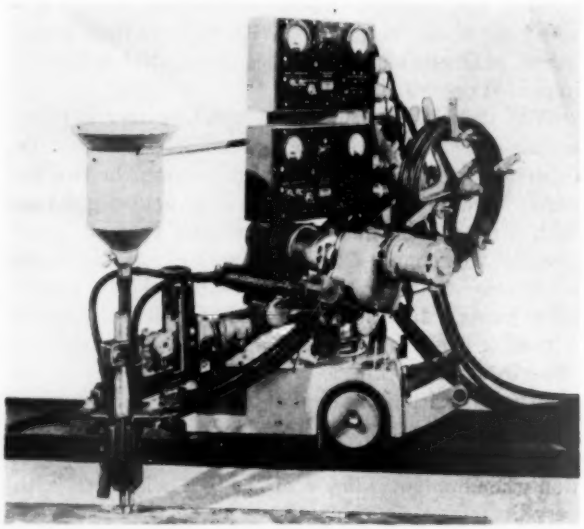

Fig. 9 "Unionmelt" DSH Dual Head Welder

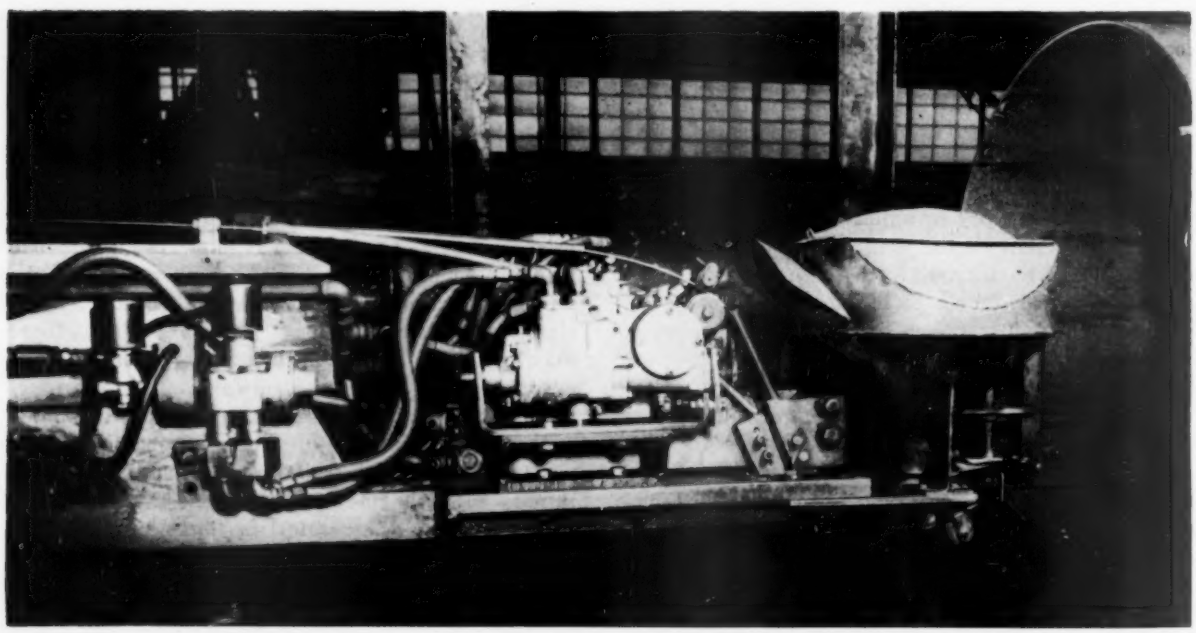

Fig. 10 Three-phase tandem welding is used to make the inside seam of high-pressure, 0.271-in. thick, 30-in. diam pipe

APPLICATIONS

Cross sections of single-pass and double-pass welds made with three-phase power are shown in Fig. 8. The single pass welds are made on $^1/_4$, $^1/_2$ and 1-in. plate. The double pass welds are made on 1- and $1^9/_{16}$ plate. The outline of the welds looks about the same as those produced by single electrode operation. The main advantage of the multiple power source, particularly with two- or three-phase welding, is the close control of weld contour and the increased speed that this technique makes possible. A typical dual welder, Fig. 9, is easily used for this type of work. It is portable, carries two controls, two wire reels and two welding heads and provides for adjusting the distance, angle of incidence and position of the electrodes with respect to the joint.

Closed-delta tandem welding is widely used in the production of high-pressure, large diameter gas transmission pipe. Figure 10 shows a duel head welder arranged for welding the inside seam. The lead electrode operates at 910 amp, 36 v; the trail electrode at 925 amp, 40 v. The ground current is 1225 amp. Approximately the same values can be used with the Scott connection. Speeds as high as 66-ipm are used to weld the 0.271- and 0.375-in. thick shells. This compares to 25 to 35 ipm using single electrode welding.

Both two-phase and three-phase power can be used for producing longitudinal joints of pressure vessels. Girth joints can be produced where the diameter is of the order of 5 ft or so. Where large numbers of vessels of essentially the same design are fabricated on a production line schedule, the increase in welding speed developed by the three-phase tandem procedure results in greatly increased output.

Fig. 11 Panels for a giant steel sphere are fabricated by a-c, a-c tandem welding

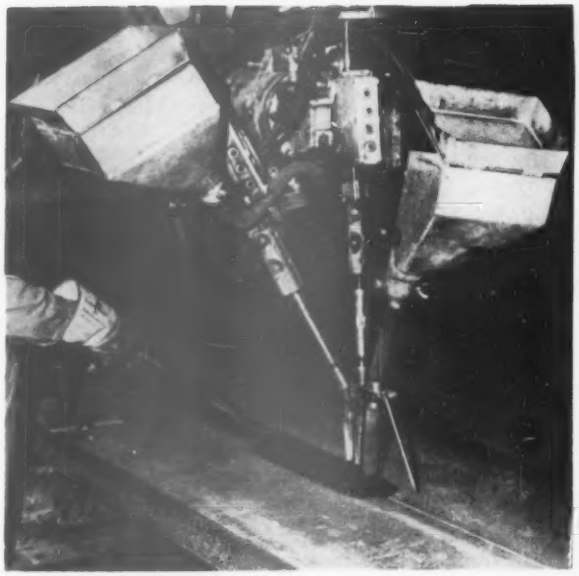

Fig. 12 Hatch covers are made from standard 12-in. channels by a-c, a-c tandem welding

Open-delta tandem welding was used for fabricating panels of a giant sphere that will be used in the testing of atomic engines. Four plates, 9 by 32 ft, were joined side to side to make a panel 32 by 36 ft. The plates were prepared with a double bevel and a $^3/_8$-in. nose. After positioning to give the proper curvature, a single pass was applied by manual arc to the inside surface of the assembly. The tandem welder, shown in Fig. 11, then made a pass on the outside surface of the assembly at a speed of 18 to 20 ipm with a current of 600 to 900

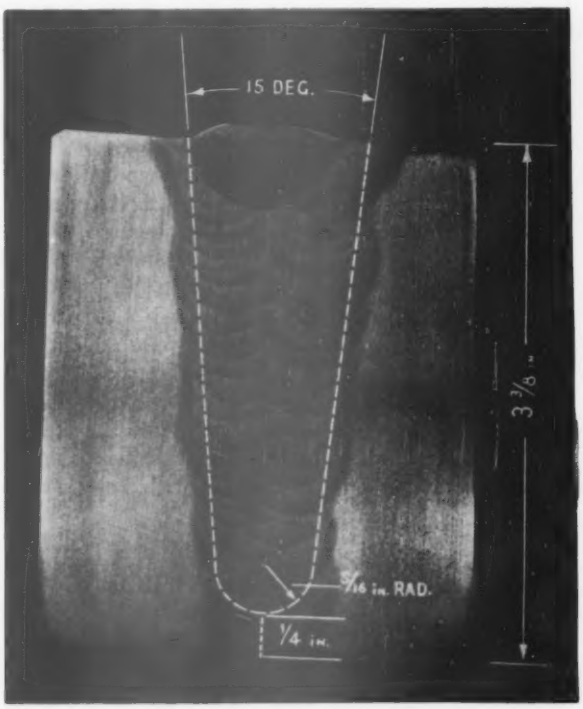

Fig. 13 Cross section of multipass a-c, a-c tandem weld in 3⅜-in. thick material

amp on each electrode. The panels were turned over again and a third pass was made with high current to obtain deep penetration through the manual bead and complete the joint. The panels were then welded into the sphere by manual arc.

Hatch covers are made by joining together channel sections as shown in Fig. 12. Two welding heads are used for a-c, a-c tandem operation. The lead electrode uses 1000 amp and the trail electrode uses 800 amp. Welding speed is 48 ipm. The advantage of the process is the deeper penetration and the higher welding speed that it makes possible.

Multipower welding is also advantageous when more than one pass is required. An example of this work is the etched cross section shown in Fig. 13. Even though the conditions are arranged so that the thickness of the individual layers is no greater than those made with single electrodes, speeds are so much higher that welding time may be cut tremendously. Welding speeds from 30 to 50 ipm are used without encountering cracking or poor weld shapes. This compares to 8–10 ipm with single-electrode welding.

ELECTRODES IN PARALLEL

The basic characteristic of parallel welding is the use of two or more welding wires connected electrically to the same power cable and fed into the welding zone by a single welding head. This arrangement gives a degree of control over current distribution that is not possible with single electrode operation. If a certain current is applied to a $^1/_4$-in. diam electrode, there will be a certain amount of heat transferred to the affected area. If, however, the same current is applied to two electrodes having the same total area as the $^1/_4$-in. electrode, the same amount of heat will be produced but the affected area on the workpiece can be altered and the pattern of heat transfer can be changed simply by varying the spacing between the electrodes.

The electrodes can be in transverse, tandem or any other position without altering the melting rates. Although either a-c or d-c welding can be used, d-c reverse polarity (DCRP) appears to give somewhat better results.

The heat transfer pattern associated with parallel electrode welding is responsible for several advantages of this process. In the tandem position, parallel electrodes operate at higher speeds than are possible with a single electrode. Electrodes connected in parallel and operating in the transverse position have a gap-bridging ability that is not possible with a single electrode.

PARALLEL-TRANSVERSE WELDING

Though parallel-transverse welding has considerable gap-bridging ability, it will not be satisfactory over completely unbacked gaps wide enough for welding composition to pass through. The weld puddle will flow through these gaps the same as it does in single-electrode welding. In many cases, adequate backing can be obtained by allowing the welding composition to pour through the joint gap and build up on the supporting table. Where no support is available, tape can be applied to the lower surface of the joint to stop the flow of welding composition.

In welding a joint with a double vee preparation where there is a support directly under the joint, higher currents can be used on joints where gaps exist than on tightly butted joints. The gap allows the granular welding composition to flow through, build upon the support below the joint and provide welding composition backing. With the tightly butted joint, current and penetration must be limited to avoid melting through the butted root faces of the joint. If the gap is wide, however, current must be high enough or speed slow enough to compensate for the change in the amount of metal required to fill the gap.

PARALLEL TANDEM WELDING

Welding with paralleled electrodes in the tandem position is generally done at higher speed than is possible with a single electrode. The increase in speed obtainable with parallel-tandem welding over single electrode welding is about 50%. In conventional single-electrode welding, the beads become undercut and ropey as the speed is raised beyond a certain point. In parallel-tandem welding, the second electrode has a flattening effect on the bead, permitting higher speeds.

SPECIAL ROD POSITIONS

Paralleled electrodes are particularly effective where the joint cannot be covered by a single electrode in a single pass. Joggle joints are an example of such an application. One electrode is arranged to strike the center line of the joint and the other is directed at the top corner of the overlying piece. Satisfactory results are obtained with the nozzle tipped forward 60 deg from the vertical and twisted 30 deg with the centerline rod leading. Within reasonable limits, the effect of rotating electrodes from the true transverse position is the same as that obtained with a smaller center-to-center distance.

APPLICATIONS

Typical of this type of work, is the use of parallel electrode welding for joining the edges of railroad car center sills as shown in Fig. 14. Standard Zee-Bar sections, $^3/_8$ in. thick and 50 ft long, are clamped in a fixture for automatic welding with the welding machine operating directly on top of the assembly. No edge preparation is used and some of the gaps are rather large. They would be extremely difficult to bridge with a single electrode, even at reduced speed. Here they are successfully joined at approximately 60 ipm by parallel-transverse welding with two $^5/_{32}$-in.-diam welding wires.

Fig. 14 Welding center sills for railroad cars by parallel transverse technique

Parallel-transverse welding is used with a specially constructed fixture to join the gunnel to the lay in the fabrication of welded steel plowshares as shown in Fig. 15. The parts are inserted in clamps on a 10-position rotating table. The assemblies are automatically welded as they pass under the welding head which is equipped for parallel-transverse operation with two $^1/_8$-in.-diam. wires. Welding speed is 28 ipm. The fixture produces 100 welded plowshares per hour; an increase of some 30 to 40 units per hour over single electrode operation.

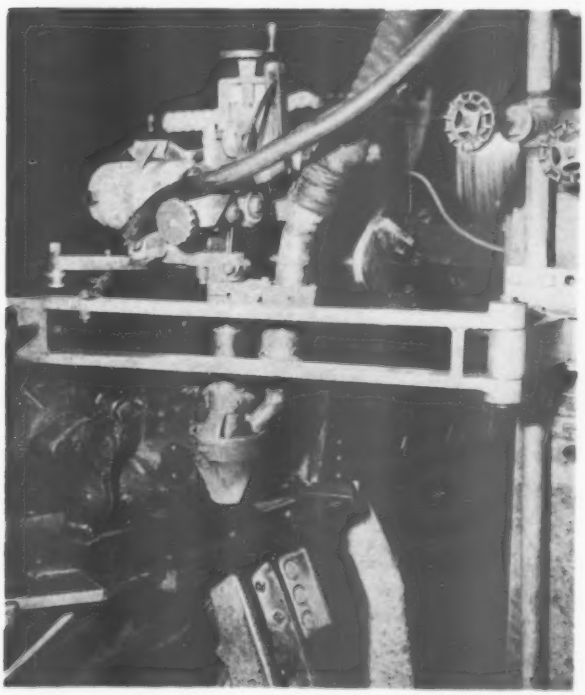

Fig. 15 Rotary fixture producing welded steel plowshares uses parallel-transverse welding

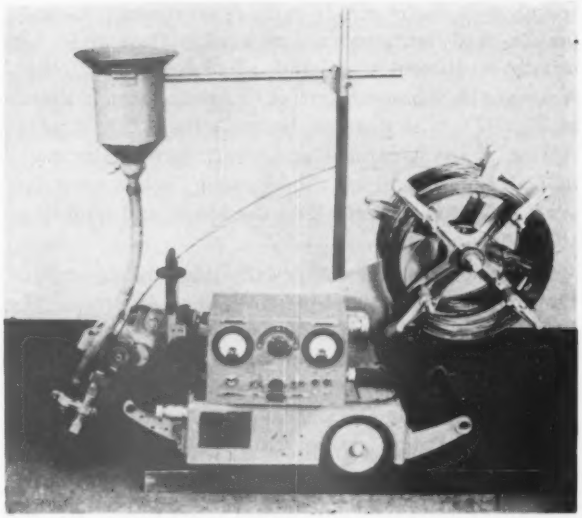

Fig. 16 Parallel welder has single head and control with two wire reels and special nozzle to handle two electrodes

Parallel welding, both tandem and transverse, is used in the construction of oil barges. The plates are prepared with a double vee and unbeveled root-face. Portable parallel welders, similar to Fig. 16 are used to weld all seams in the assembly. The first pass is made with the electrodes in the transverse position, the second with the electrodes in the tandem position. Welding is done at the rate of 260 ft per operator, per 8 hr shift. Formerly with single-electrode welding, the best rate was 180 fph per operator per 8-hr shift.

SERIES-ARC CONNECTION

In series-arc welding, each electrode has its own feed motor and voltage control and operates independently of its partner. The power supply cable is connected to one welding head. The return power cable is connected to the second welding head instead of to the workpiece as it would be in conventional welding. The two electrodes are in series. The welding current

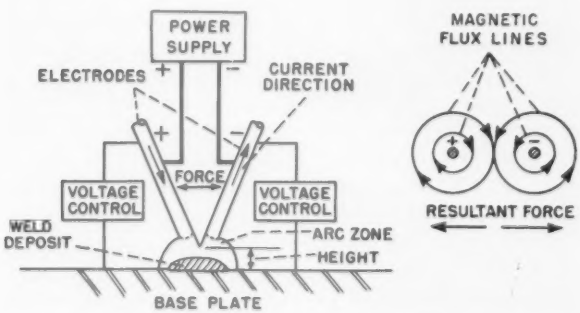

Fig. 17 Schematic drawing (left) of series arc welding. Diagram of magnetic field (right) showing force of repulsion acting on arc stream

travels from one electrode to the other through the weld puddle and surrounding material. The wires are usually positioned at an angle of 45 deg to each other. A schematic representation of this connection is shown in Fig. 17. The distance between the point of intersection of the electrodes and the surface of the work, indicated as height on this drawing, is the most important factor in controlling the shape and quality of the deposited metal.

Another factor that affects the shape of the weld is the magnetic field that surrounds the arc stream. In series-arc welding, the polarity of each electrode is opposite. This creates a force that tends to spread the ends of the arc away from each other and thus causes a fanning or spreading of the arc zone.

Either alternating or direct current can be used depending on the application. Alternating current is preferred for applying mild steel or stainless steel, while for nonferrous applications, direct current should be used. When welding with direct current, penetration is slightly deeper under the positive electrode than under the negative. This condition can be minimized when laying a multipass, wide deposit by positioning the heads so that the positive electrode is located over the previously deposited metal and thus a deposit can be produced with an even penetration into the base metal.

The series-tandem technique is used for welding of joints in members that are too thin for single-electrode welding, or where it is impossible to provide adequate backing.

With the electrodes in the transverse position, a wider deposit is produced with penetration and dilution kept to a minimum. For this reason the process is particularly valuable in the cladding of surfaces. An interesting example is the use of this method to apply a layer of stainless steel to a large forging that will be used in the chemical industry. The forging is a cylindrical section, 54 in. in diameter and 36 in. thick. Specifications call for Type 316 stainless steel to be deposited in a layer 1 in. thick over a circle 40 in. in diameter centered on the face of the forging. No positioner of adequate capacity was available for turning the forging and so it was necessary to do the work with the disk stationary. First, a number of longitudinal overlapping welds were applied to the center of the face to produce a circular pad about 18 in. in diameter. Figure 18 shows the general layout of the equipment with two welding machines yoked together for making this deposit. When this pad was completed, a post was mounted at the center and the welding heads were attached to it by a radius rod as shown in Fig. 19. The balance of the cladding was applied then as a series of concentric deposits. To obtain a weld deposit that was equivalent to Type 316 stainless steel, a Type U-309-Mo welding wire wax used. This is a Type 309 steel with a nominal 2% molybdenum added. The smooth, regular surface of the weld will require little machining to finish it to the required thickness.

Cast steel valve wedges of the type shown in Fig. 20 are surfaced by the series arc method. These gate wedges usually range from 4 to 30 in. in diameter. The wear surfaces of the wedges are protected by a deposit of Type U-430 welding wire. Those wedges that re-

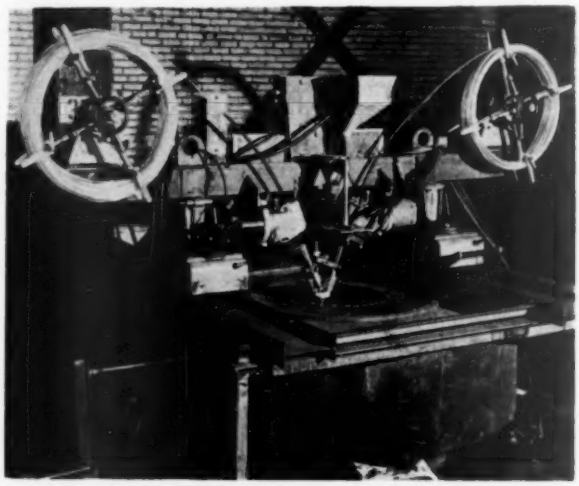

Fig. 18 Two-welding machines yoked together for making a series-transverse deposit on a large carbon-steel forging

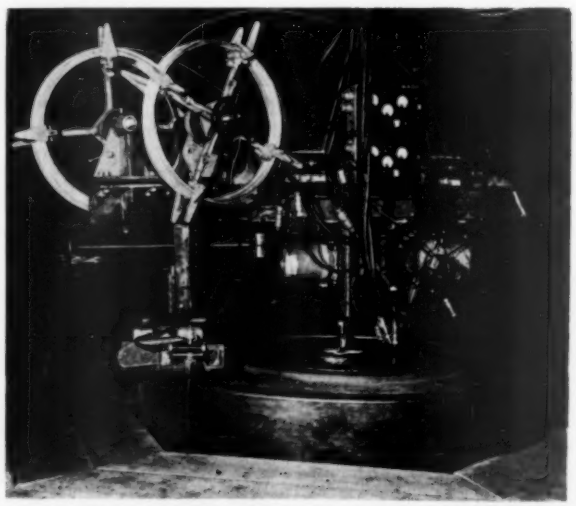

Fig. 19 Larger concentric deposits are made on this forging (see Fig. 18) by using a center post and radius rod to guide the two welding heads connected in series

Fig. 20 Cast-steel valve wedges are protected by depositing a layer of corrosion-resistant metal on the wear surface. Before welding (left); as-welded (right)

quire finished faces up to 1 in. wide are completed in one pass per face. The largest size wedges usually require a face about $1^1/_2$ in. wide and are completed by applying two overlapping deposits.

Another example of valve facing may be seen in Fig. 21. Shown here is a cross section of a carbon steel seat ring which has been clad with "Hastelloy" alloy B. Notice the flat smooth deposit and the low dilution as indicated by the small amount of base metal melted into the weld bead. The dotted line indicates the original grooved surface. Formerly, it was required that such a groove be machined for manual deposition of the corrosion-resistant "Hastelloy" alloy B. In this instance, as in several of the wedge applications, the use of this process eliminated the necessity of premachining the part before welding.

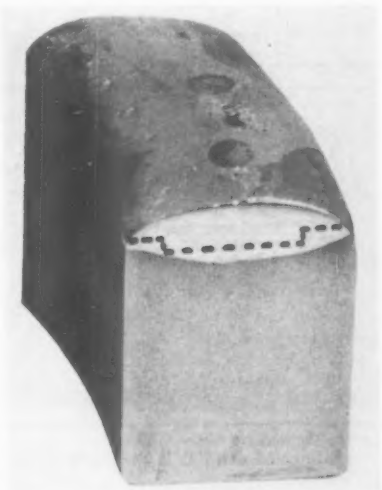

Fig. 21 Cross section of carbon steel valve seat ring, faced with a single-pass deposit of "Hastelloy" alloy B

The equipment that was used for series transverse cladding of valve seat rings is shown in Fig. 22. Two "Unionmelt" DS welding heads are mounted on the frame with a vertical and horizontal cross slide to provide the necessary adjustment. The valve ring is fastened to the table of the positioner with an air chuck. The ground connection at the right is used to obtain a reference voltage for the operation of the control units and is attached to the center post of the chuck during welding.

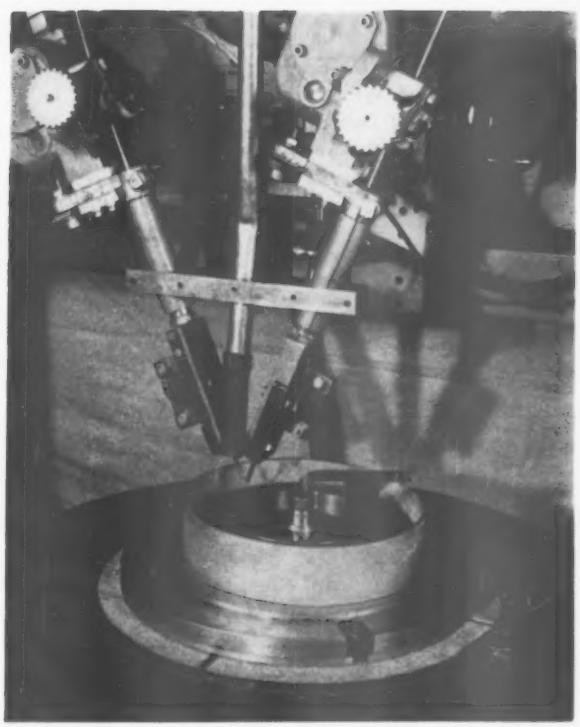

Fig. 22 Dual welding head installation for applying "Hastelloy" alloy B to carbon-steel valve rings

Turbine blades, propellers, wicket gates and other surfaces in contact with liquids flowing at high velicity are particularly subject to corrosive and erosive action. Series-transverse welding is used to apply protective alloys to the large surfaces of equipment that is subject to this effect.

Kaplan turbine blades of cast steel, shown in Fig. 23, are surfaced with Type U-304 welding wire. This material is applied to an area approximately 24 in. wide

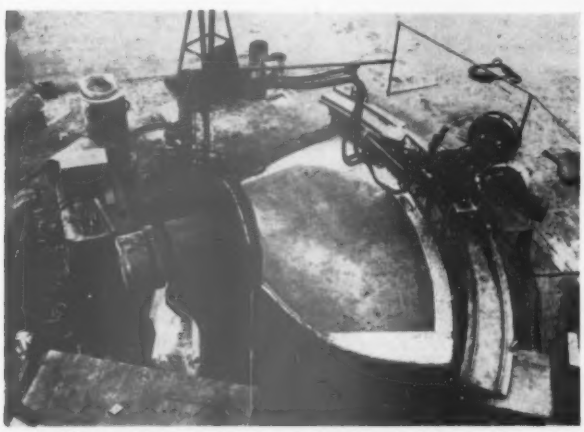

Fig. 23 Turbine blade protected around the ends and along the radial edges by a deposit of Type U-304 weld metal

Fig. 24 Compound nozzle of dual welding machine for making overlapped deposits along the edge of a giant turbine blade

along the 11-ft periphery and additional deposits are made inward toward the hub along the radial edges of the blade. A special fixture was devised to manipulate this 22-ton forging so that the weld zone could be maintained in a flat position as shown in Fig. 23. A special curved track was made to guide the dual welding machine around the ends of the blades, concentric with the curved periphery. Figure 24 shows a closer view of the dual nozzle and also reveals how the beads are carefully lapped to obtain a smooth deposit.

Cast-steel wicket gates used in the hydroelectric industry are protected with deposits of stainless steel. These cladding deposits are usually made in two overlapped passes and are placed along the mating surfaces of each gate. The area presently being clad by the series-transverse method is about 8 ft long.

Basically, multiple electrode welding has provided an extraordinarily effective means of controlling penetration, reinforcement, weld shape and dilution. Any of these multiple electrode methods has the advantage of high welding speed. Compared with single electrode operation, parallel welding is about $1\frac{1}{2}$ times as fast and multipower welding is more than twice as fast. In cladding applications, the series-arc method permits low dilution deposits at twice the single electrode rate for the same current level. The applications cover a wide field and when we consider combinations of these techniques, the field is wider still. In many aspects, multiple-electrode welding is an entirely new welding method, and as such it can open the way to new procedures, new products and new fields for welding in the metal-working industry.

Carbide Segregation in 1¼Cr-½Mo Steel Pipe

Discussion by A. B. Wilder

A WELD in $10\frac{3}{4}$-in. OD by 1.125-in. wall pipe to ASTM Specification A158, Grade P11 ($1\frac{1}{4}$ CR – $\frac{1}{2}$ MO) was examined to determine the effect of carbide segregation on the properties of the pipe joint. This weld was similar to the weld described by Messers I. A. Rohrig and H. S. Blumberg.

The pipe material was annealed at 1500° F before welding. The joint was preheated to 500° F and welded with 2 CR – $\frac{1}{2}$ MO filler metal. The weld was heated to 1500° F, cooled at 200° F per hour to 800° F and then air cooled. The length of exposure of the pipe while in steam service at 950° F was not known.

Stress rupture properties

Heat treatment	*Stress for rupture at 950° F*	
	1000 hr	*10,000 hr**
Parent metal-weld metal†	35,000	29,000
Parent metal normalized 1675° F and tempered 1375° F	34,500	28,900
Parent metal annealed 1500° F	52,000	44,000

Heat treatment	*Stress for rupture at 1050° F*	
	1000 hr	*10,000 hr**
Parent metal-weld metal†	19,500	14,200
Parent metal normalized 1675° F and tempered 1375° F	17,700	12,800
Parent metal annealed 1500° F	24,900	16,700

* Obtained by extrapolation.
† Annealed at 1500°F as described above.

The creep rupture properties of the weld were not adversely affected by carbide segregation. The samples were provided by the Grinnell Co. and the tests were performed by D. T. Boughner, K. B. Dempsey, M. F. Baldy and W. R. Foley of the National Tube Division Research Laboratory.

Chemical composition, %

	C	*Mn*	*Si*	*CR*	*MO*
Pipe ladle	0.10	0.48	0.78	1.20	0.53
Pipe, check	0.13	0.51	0.62	1.29	0.55
Weld metal	0.16	0.52	0.24	2.09	0.46

Tensile properties of parent metal

Heat treatment	*Yield strength 0.5% elongation under load, 1000 psi*	*Ultimate strength, 1000 psi*	*Elongation % in 1 in.*	*Reduction of area, %*
Normalized 1675° F and tempered 1375° F	40.6	68.4	43	75
Annealed 1500° F	36.8	73.1	44	71

In the creep rupture tests of the parent metal-weld metal all specimens were machined, 0.250 in. diam and $4\frac{3}{4}$ in. long, to determine if fracture would occur in the decarburized or segregated zone. The parent metal-weld metal tests all fractured outside of the decarburized or segregated area and they did not break inside the weld section.

A. B. Wilder is Chief Metallurgist, National Tube Division, United States Steel Corp., Pittsburgh, Pa.

Paper by I. A. Rohrig and H. S. Blumberg was published in THE WELDING JOURNAL, 32 (9), 815–822 (1953).

Author's Reply

The data furnished by Mr. Wilder are welcome additional evidence that the carbide banding and decarburization observed in the samples apparently does not have a significant effect on the physical properties of welded joints in P-11 pipe material. In particular, it is reassuring to have the stress-rupture data at 950 and 1050° F for samples of the affected pipe material after it had been in power plant service at 950° F; in general, the values reported are better than published values for new material.

Fig. 1 The MacArthur Bridge

The Reconstruction of the MacArthur Bridge

Welding permits the economical reconstruction of old highway and pedestrian bridge across the Mississippi River

by Ned L. Ashton

THE bridge described in this paper is the MacArthur Highway Bridge across the Mississippi River at Burlington, Iowa, as shown in Fig. 1.

It was built in 1916 for highway and pedestrian traffic by The Citizens Bridge Co., Inc., of Burlington, Iowa, under the leadership of J. A. MacArthur, then President of the Commercial Exchange and who later became President of the Bridge Co. and for whom the bridge was named in 1923.

The original Bridge Co. first issued $95,000 worth of preferred stock and $25,000 worth of common stock and then later floated an $80,000 bond issue to complete the original financing of the bridge.

Ned L. Ashton is Consulting Engineer, Iowa City, Iowa.

Scheduled for presentation at the AWS National Spring Meeting to be held in Buffalo, N. Y., May 4-7, 1954.

The bridge was completed and opened to traffic as a toll bridge in 1917. According to ordinance, ownership of the enterprise was to revert to the City of Burlington when the outstanding indebtedness of the company had been retired. In August 1923 the income from the bridge had automatically retired both the bonds and the common stock and the City of Burlington then secured the bridge by the expenditure of only $95,000 which was raised by a special taxation plan that remained in force for only two years longer.

Since that time the bridge has continued to operate as a toll bridge and has produced over $4,500,000 of revenue for the City of Burlington to use in lieu of other forms of taxation and since the reconstruction of the bridge is also financed by the issuance of $900,000 worth of Bridge Revenue Bonds. This project has certainly paid for itself.

The original bridge had a timber deck with timber

curbs and a 4-ft timber sidewalk running between the main span trusses as shown in Fig. 2. Since the trusses were spaced at 26 ft centers, this only left room for a 19-ft roadway with less than 6 in. for curb clearance. Therefore the new sidewalk was cantilevered on the outside in this reconstruction so that all of the space between the trusses could be used for the new roadway as shown in Fig. 3 and as seen from the river in Fig. 4.

The bridge was designed and built originally by the Wisconsin Bridge and Iron Co. of Milwaukee, Wis., in accordance with the conventional practices of that time for projects that were somewhat cramped for finances.

The original stress sheets indicate that provision was made in the design of the main spans for live loads of 1400 lb per linear foot of bridge, a dead load of 2200 lb per linear foot of bridge, a wind load of 150 lb per linear foot on the top laterals and 300 lb per linear foot on the bottom laterals and that there was at least partial provision for a future street car loading on the downstream half of the roadway. The other half of the roadway was for light traffic and there were no provisions for such things as impact or portal action or heavy modern trucks.

Even worse, some of the computed stresses were inconsistent in adjacent members, some of the sections that were provided in the main members were never connected, and the single plane portals and lateral bracing systems were ineffective to the extent that the whole bridge vibrated precariously and continuously under the passage of every truck.

Thus it was found when the author first looked at the bridge in June 1951, after the Wisconsin Bridge Co. engineers had advised the City of Burlington to

"Immediately restrict the use of this bridge for traffic by not allowing any vehicle weighing over 6000 lb total weight to cross the structure at any time until the new floor and repairs are made.

"You are assuming grave responsibility by now allowing almost unrestricted traffic."

At that time they also advised that while the bridge had given 35 yr of excellent service it was now entirely outmoded in its capacity to serve unrestricted, present-day, heavy, fast-moving vehicular traffic and that it was not practical to reconstruct the bridge to accommodate H-20 loading.

Thus, the strengthening and reconstruction of this bridge began as a formidable assignment upon which the author had the pleasure of staking his reputation for the past two years.

The work involved was equivalent to designing several new bridges since the MacArthur Bridge is 2460 ft long and consists of beam spans, six varieties of girder spans and three lengths of deck truss spans in addition to the 1000 ft of main cantilever spans all of which were first checked for existing conditions and

Fig. 2 The old timber deck

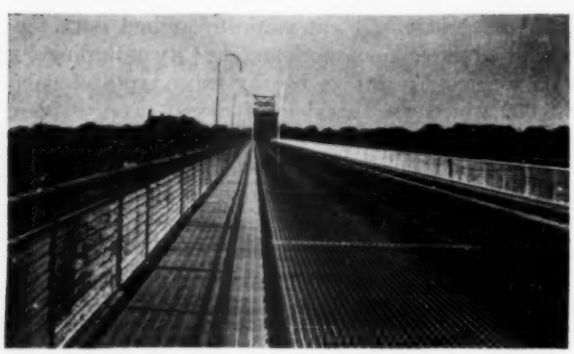

Fig. 3 The new steel deck

Fig. 4 The new lateral bracing and cantilevered sidewalk

then strengthened and refigured for the new and final conditions.

The new conditions were also figured and complete plans were drawn for both a 20-ft roadway with the sidewalk inside and for the 22-ft roadway with the sidewalk cantilevered outside that was finally adopted after bids were taken on both alternates.

The planning stages consumed the time from June 7, 1951 until Nov. 15, 1951 when the bids were first received but, since only one irregular bid of $950,000 was received at this letting for work that was estimated at about $650,000 it was rejected and the project was readvertised for a second letting on Dec. 13, 1951. At the second letting, four bids were received and the contract for the reconstruction of the bridge was finally awarded to the Vogt and Conant Co., Structural Steel Erectors of Cleveland, Ohio, on Jan. 17, 1952 for $806,-200.

During the next few months shop drawings were made and approved, steel allocations were obtained and the steel was fabricated, scheduled for erection beginning on June 1, 1952. Then came the steel strike and further delays were suffered so that actual erection did not commence until late in November 1952.

The work finally commenced with the reconstruction of three 30-ft beam spans and the concrete work on the west approach.

The traffic was all diverted to a single lane on the north side of the bridge controlled by synchronized stop-and-go signal lights located at both ends of the bridge. These lights were set to let the east-bound traffic go in one direction from the toll house control at the west end of the bridge for five minutes before the stop light would come on at the west end and then there would be a $2^1/_2$-min interval for clearing all of the east-bound traffic off the bridge before the "go" light would turn on at the east end of the bridge for 5 min of west-bound traffic followed in turn by the "stop" light and another $2^1/_2$-min interval for clearing the west-bound traffic.

All of the new materials were taken out on the bridge and the old salvaged material removed during these same $2^1/_2$-min intervals between the traffic. The material trucks and cranes would join the parade at the end of each direction of traffic and park into the open areas of the working lane either ahead of or behind the work and when necessary the clearing interval was extended slightly by manually retarding the next "go" light. In addition, flagmen were also used to protect the traffic at all unguarded openings in the deck.

During the first phase of the diversion, the old sidewalk was removed and the handrail was moved out 3 ft 3 in. on the south side of the bridge to make room for the wider roadway and for the new sidewalk in the new location. Once this work began it progressed continuously all the way across the river on the south side of the bridge removing the old brackets, adding the new sidewalk brackets and floor beam extensions and erecting the new sidewalk, south curb supports and re-erecting the old handrail.

The old timber floor was sawed in half over the center of the beam nearest the centerline of the new roadway so that the south half of the old roadway floor could be removed for strengthening the beams underneath while the traffic continued to use the north half of the old roadway. Where necessary the edge of the old floor was temporarily reinforced with an additional temporary stringer under the roadway. Later the traffic was diverted to the temporary flooring on the south half of the bridge while the north half of the roadway was repaired in a similar manner.

A view of this phase of the work is shown on Fig. 5.

Fig. 5 The traffic diversion 30-ft beam spans

To begin with, 15 sections of the permanent decking were cut in half for use as temporary decking. Figure 5 shows this temporary decking in place over the south portion of the roadway while the north side is being strengthened.

These spans consisted of two 26-in. I @ 90# beams spaced at 16-ft. centers with 15 in. I @ 42# interior floor beams and 15-in. channel @ 33# end floor beams and with 8 I @ 18# stringers at 2 ft 9 in. centers under the timber floor. The 8-in. stringers and 15-in. floor beams rated about H7 or H8 at normal stresses and the main girders about H-14.

They were strengthened by replacing all old 8-in. stringers with new 10 I 25# stringers, by deepening the 15-in. floor beams to 25-in. beams with a new web and top flange extension as shown on Fig. 5 and by deepening the main girders from 26 to 31 in. by adding a new continuous 5-in. WF 27# structural tee section top flange fillet welded to the top of the I beams. This was butt spliced by welding to run continuously for the full length of the original 90 ft of the three simple beam spans. The bottom flanges were also blocked apart and spliced for continuity by welding at the supports. In this section of the bridge, the north handrail was also moved out 9 in. from its original location to make room for new 10-in. bent plate curbs. These new curbs had 18 in. of horizontal clearance between the face of the curb and the handrail.

Then, as the final step, the temporary half-width pieces of decking were removed and replaced one at a

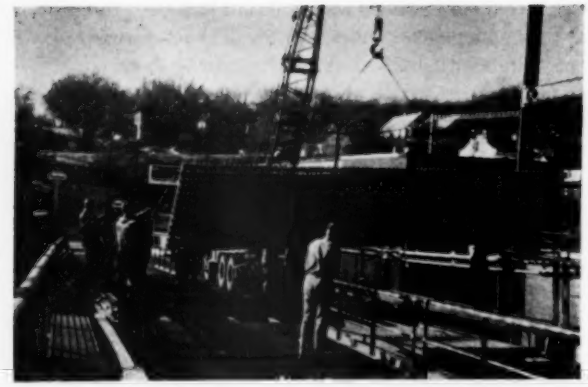

Fig. 6 Placing the new steel decking

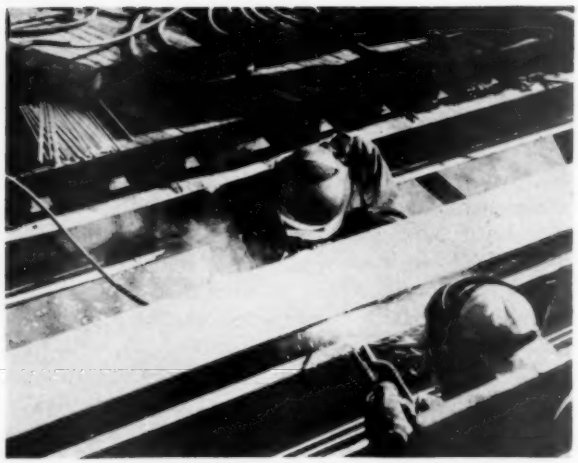

Fig. 7 The new tee-top flange

time with permanent pieces of full width decking as shown in Fig. 6 and the whole operation moves ahead across the bridge.

It requires less than one minute to remove a temporary piece of decking and replace it with the permanent piece with everything in readiness. Thus it was easy to accomplish this operation after the last vehicle had passed going east or west and before the next one came from the opposite direction in the normal traffic interval. The pieces of decking were temporarily wedged and tack welded down and the permanent fastening came along later at the leisure of the welders.

Following the beam spans, the next 250-ft section of the bridge in the west approach consists of a 40-, 28-71-, 56- and 56-ft span series of deck plate girder spans and the east approach contains two 50- and four 76-ft 3-in deck plate girder spans.

All of these spans were below standard and had to be strengthened.

The top flanges of all the girders were badly corroded from being in direct contact with rotten timber sleepers throughout their 30 yr of life and in many instances had lost at least 50% of the outstanding legs of the top flange angles from corrosion.

This metal was all restored and the girders were deepened by adding new tee section top flanges with the stem fillet welded to the web as shown in Fig. 7.

TABULATION OF DESIGN VALUES

SEC	COMPOSING PARTS	W"/FT	AREA	I	C	S	SHEAR	MOMENT
1	4L 6"x6"x7/16 WEB 80"x5/16	153·8	39·96	36967	41·04 C 39·21 T	900" C 942 T		500"C 870"T
2	4L 6"x6"x7/8 WEB 80"x5/16 ST 5"W 27	180·8	47·90	50532	38·59 C 46·72 T	1310 C 1082 T		2180"C 1805"T
3	4L 6"x6"x7/8 WEB 80"x5/16 ST 5"W 27 2 L 4"x3"x3/8" BARS 1L 4"x3"x1/4	189·2	50·34	51673	37·60 C 47·70 T	1374 C 1085 T		2290"C 1810"T
4	4L 6"x6"x7/16 WEB 80"x5/16 ST 5"W 27 2 L 4"x3"x3/8" BARS 1L 4"x3"x1/4 14"x1/2" COV PL	213·5	57·34	65754	43·47 C 42·34 T	1513 C 1550 T		2525"C 2581"T

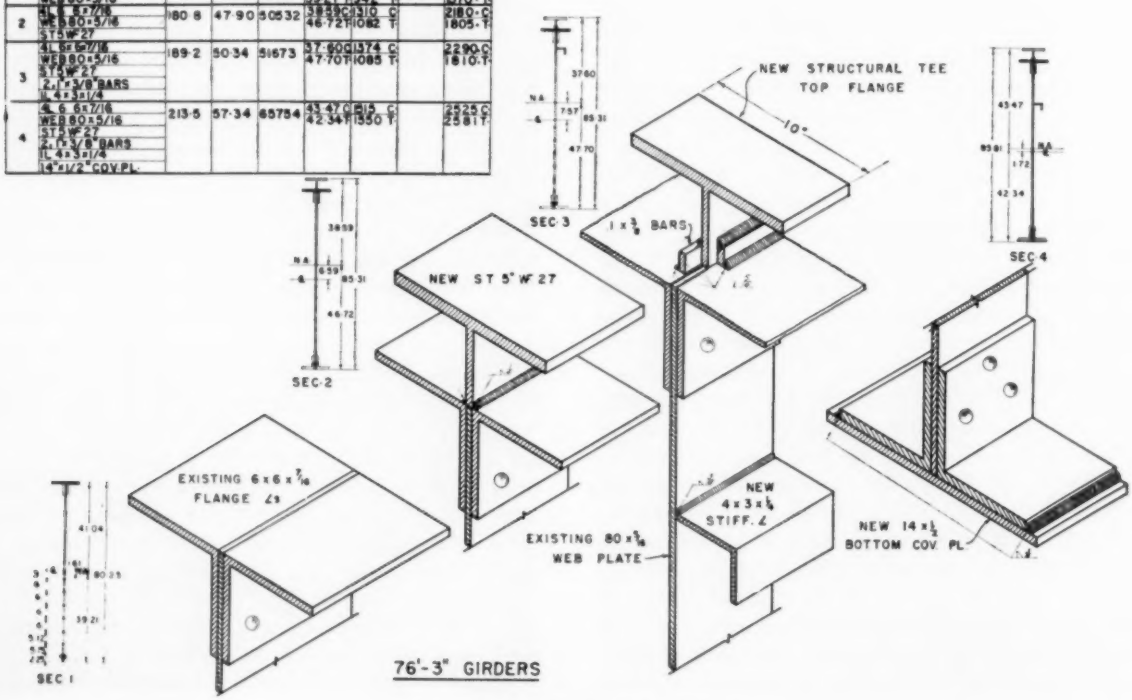
NEW STRUCTURAL TEE TOP FLANGE
10"
1 x 3/8 BARS
NEW ST 5" W 27
EXISTING 6 x 6 x 7/16 FLANGE ∠s
EXISTING 80 x 5/16 WEB PLATE
NEW 4 x 3 x 1/2 STIFF. ∠
NEW 14 x 1/2 BOTTOM COV. PL
SEC 1
SEC 2
SEC 3
SEC 4
76'-3" GIRDERS

Fig. 8 The girder reinforcements

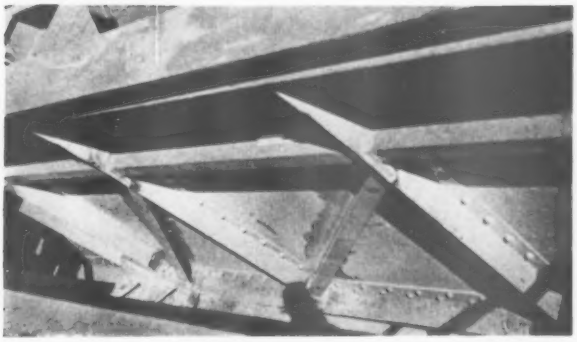

Fig. 9 The new stiffeners

These tees were supported with temporary vertical bars and tack welded in place for final welding. In cases where the corrosion was excessive additional 1 x $^{3}/_{8}$-in. bars were used to fill in the gap between the stem of the tee and the back of the angles and two fillet welds were used on each side of the web as shown in Fig. 8.

The deeper girder webs were also reinforced by welding new horizontal and diagonal angle stiffeners on the inside faces of the webs as shown in Fig. 9. New bottom cover plates were welded to the bottom flanges, new end bearing stiffeners were added and from 30 to 40 more web rivets were added in each web splice in every girder to complete the girder reinforcements. The web rivets were required to develop the bending strengths of the webs.

By these means the strength of the old 76-ft girder spans was increased by more than 60%, as shown in Fig. 8.

When the deck was removed, some of the old 76-ft span girders were found with both girders buckled as much as $1^{1}/_{2}$ in. out of line in 15 ft as shown in Fig. 10, and it was the composite action and lateral strength of the deck itself that kept the bridge from collapsing.

Fig. 10 A buckled girder flange

Extra strengthening was therefore provided at these points in the form of additional new cover plates that were plug and fillet welded to the girders in the damaged areas before the new tee flanges were placed on top. Then after the new flange was in place there was no longer any danger.

The new sidewalk and curb brackets were made of pieces of 8-in. I-beams supported on tee-section knee braces as shown on Fig. 11. These brackets were tied back to the floor-beam bracing frames with pieces of the old bracket angles by welding.

Fig. 11 The curb and handrail brackets

Figure 11 shows the new deck on the west approach just as the last 56-ft girder span was being completed on Mar. 30, 1953. Timber fillers were used between the temporary pieces of decking to give more room and expedite the placing of the permanent decking.

A typical parade of heavy traffic has just been given the "go" light in this picture. In one instance nine large heavily laden trucks carrying explosives to the Iowa Ordinance Works, just west of Burlington, came onto the bridge on a single "go" signal, from the east, without any other vehicles of any kind in between the trucks.

Following the girder spans the next sections of the bridge are a 140-ft deck truss span on the west approach and a series of 120-, 140-, 140- and 175-ft deck truss spans on the east approach.

The floor system on these spans consisted of 8- and 10-in. I-beams and channel stringers supported on 18-in. I 55# floor beams at 17-ft 6-in. centers on trusses at 16-ft centers. Both the trusses and the floor beams of these spans were adequate for modern traffic and only the 8-in. beams and channels had to be replaced and the floor beams lengthened.

The floor-beam extensions were made by butt welding additional pieces of tapered beam brackets 3 ft 3 in. long to the ends of the original beams on the sidewalk side and 9 in. long on the north side as shown in Fig. 12. The 8-in. beams were replaced with 10-in. I-beam stringers taken from the main spans.

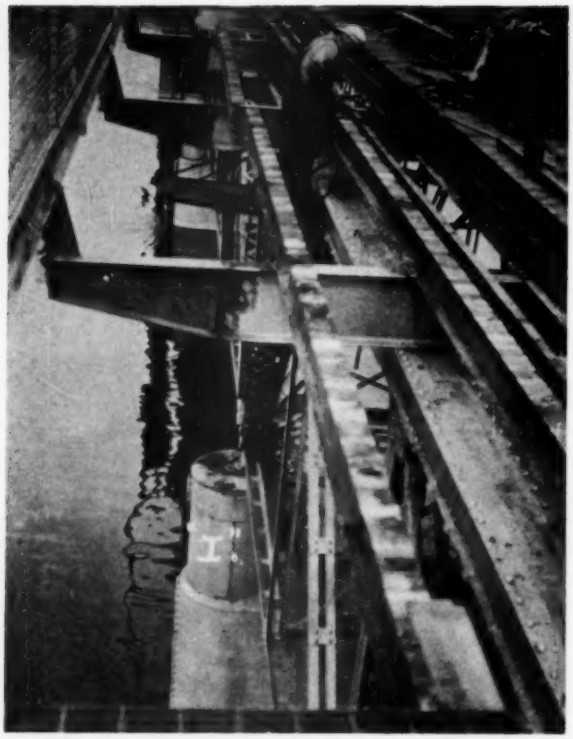

Fig. 12 The floor-beam extensions

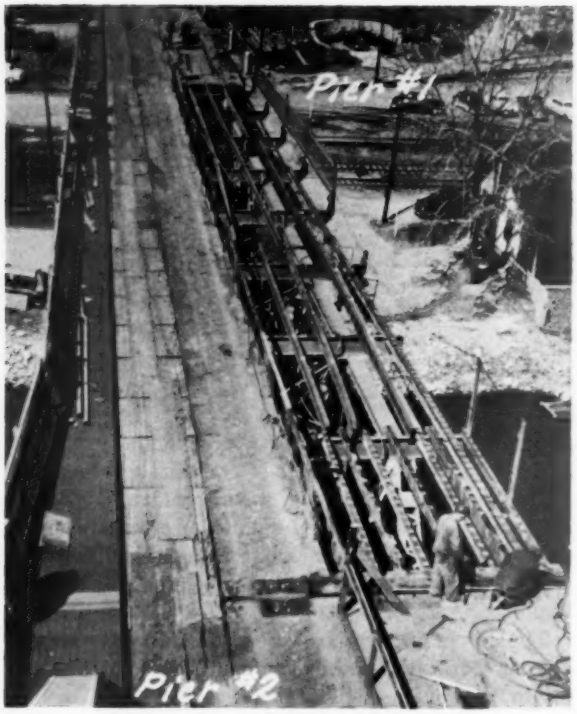

Fig. 13 The second stage on the 140-ft deck truss span

Figure 13 shows the 140-ft span on the west approach during the second stage while the stringers were being replaced on the north side of the roadway. In the first stage, the old sidewalk was removed so that the floor beams could be extended and a new stringer added under the edge of the widened roadway and then the roadway was temporarily filled back in.

All of the new stringers were spliced by butt welding at about the one-fourth span points. The old stringers that remained in place were spliced over the floor beams with special splice plate weldments as shown in Fig. 14 to obtain full continuity. In this case two pieces of 10WF 25# beams that had previously been coped to a depth of 7 in. were butt welded and spliced as shown.

The only other complications that developed during the reconstruction of the deck truss spans were as follows:

At Pier I, the ends of both 140-ft truss spans had to be jacked $6^5/_8$ in. north to correct for an old pier displacement as shown on Fig. 12, that had been caused by an ice jam in 1929. For this the spans were lifted with temporary jacking brackets while the masonry plates were changed to a larger size. The piers themselves were rebuilt in 1929.

The expansion rocker shoes for the 175-ft deck span at Pier 5 were jammed and this span also had to be lifted while the shoes were reset. New hold-down anchors were provided at the ends of the main span by means of special 12-in. end stringers on the deck spans so that the deck truss spans would have to be lifted before the cantilever trusses could be upset. These stringers rest on top of the main span floor beams and were anchored down to the deck spans with four new 1-in. square anchor rods over each deck truss.

All other major operations were confined to the reconstruction of the main spans wherein many deficiencies were corrected.

The main span trusses are 1000 ft long and the trusses are spaced 26 ft apart. The channel span consists of a 216-ft suspended span supported from two 132-ft long cantilever arms. It is 480 ft long and is anchored with 260-ft end-span anchor arms. The suspended span is subdivided into 10 panels, 21 ft $7^1/_8$ in., while the cantilever arms each have 6 panels at 22 ft and the anchor arm is subdivided into 12 panels at 21 ft 8 in. Expansion joints are provided at both ends of the suspended span and at the shore ends of the anchor arms while this portion of the bridge is fixed to the main channel span piers 3 and 4.

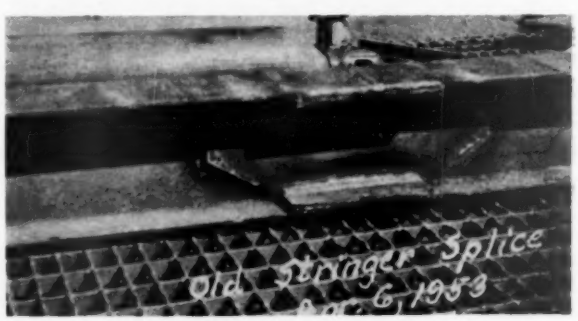

Fig. 14 The stringer splice

Fig. 15 Reinforcing for L16-U18 truss members

On these spans the stringers under the north half of the roadway, the main floorbeams and the hangers all had an original inventory rating of only about H-10 while most of the rest of the trusses, excepting the portal members and only a few other exceptions, were good for H-20 at normal stresses. At operating rating stresses, allowing 50% increased stresses above normal, the floor system on the main spans rated about H-17 and was thus temporarily safe for the traffic. In the reconstruction all members that were deficient for safe operating conditions were strengthened up to an inventory rating of H20-S16 at normal stresses.

The work on these spans began with the removal of the old sidewalk and the construction of the new sidewalk cantilevered outside the downstream truss as shown in Fig. 4. At this time two new 12 in. I 31.8# roadway stringers were installed in place of the old sidewalk stringer channels, the curb and sidewalk supports were installed and the wider roadway was temporarily filled in with salvaged timber from the old roadway. This work proceeded straight on across the river from one end of the spans to the other.

At the same time, all of the deficient members in the sidewalk truss were reinforced to gain strength in the bridge.

Figure 15 shows the new sidewalk brackets and the addition of one of the new 14- x $^1/_2$-in. reinforcing

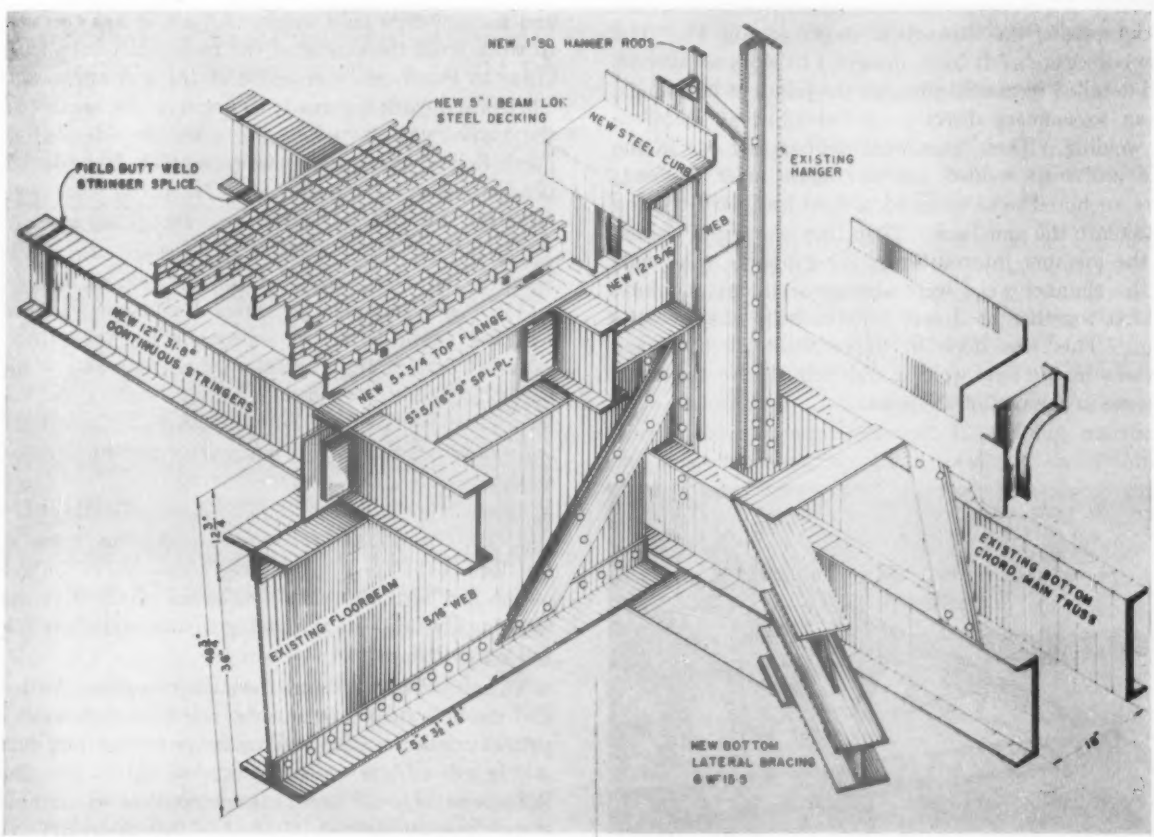

Fig. 16 The new floor-beam and hanger details

plates on the portal members L16-U18 at the end of the cantilever arm. All of the portal members were weak because there was no allowance made for portal action in the original design in any of the truss members. These plates were inserted within the members and first butt welded directly to the gusset plates of the original truss joints at L16, for the end connection, and then fillet welded along both edges to the backs of the channels.

Truss members U6-L4 and U8-U10 were also deficient for the axial stresses. Two 5- x $^1/_2$-in. reinforcing plates were added to members U6-L4. These plates were also placed on the inside of the member and butt welded to the gusset plates.

All vertical hangers were reinforced with either two new 1-in. square rods or 1-in. round rods extending from the floor beams to the next supporting joint above as shown on Fig. 16.

Top chord members U8-U10 on the anchor arm as shown on Fig. 17 were the weakest members in the truss. They had to have 16 sq in. of metal added to members that only had 20.35 in. net section in the first place. They consisted of two 15-in. @ 33# channels and a 24- x $^5/_{16}$-in. cover plate for members with a stress of 755 kips in tension. For live load, they had an inventory rating of only H4.4, whereas the members that they were connected to were safe for an operating rating of H-24.

The new metal in this instance was added in the form of four 4- x 1-in. bars welded to the sides of the member of the webs of the channels as shown on Fig. 17. The new bars were 47 ft long, designed to work as eyebars and detailed to extend through the joints at both ends, so as to connect directly to the adjacent members by welding. These bars were deliberately cut in the field and butt welded together again after the ends were anchored so as to shrink a dead load participation stress into the new bars. Then they were fillet welded to the member intermittently for support. The ends of the channel webs were also grooved out and butt welded together at Joints U10 to help reinforce the joint. This was done in hopes that the shrinkage stresses in the new weld would help relieve the overstresses in the rest of the joint.

Fig. 17 The top chord reinforcing U8-U18

Another serious deficiency was discovered in the connections of the members to the gusset plates in the main bottom chords of the cantilever and anchor arm trusses for members L8-L10, L10-L12 and L12-L14. These members consist of two 15 @ 50# channels with two 12- x $^3/_8$- or $^7/_{16}$-in. plates inside the two 12- x $^1/_2$-in. plates outside between the channel flanges. The inside plates were in the same plane as the gusset plates at the truss joint so the detailer just stopped them at the edge of the gusset plates and never connected them at all at five places in each anchor arm truss. Since these unconnected plates represented 20% of the section of the main member this lack of continuity caused many points to have unusually high stress concentrations in the remaining portions of the main bottom compression chords.

At first thought it would seem easy to butt weld the plates together but after second thought butt welding was not advisable since it would shrink more compression stresses into the remaining portions and might even collapse the whole bridge. Therefore, these connections were made by bridging the unconnected gaps with new 4- x 1-in. bars fillet welded to both sides without attempting to equalize the dead load stresses.

As the sidewalk truss was being strengthened the reconstruction of the roadway began on the south half of the suspended span until the reinforcing of the south truss was completed.

Since the old timber decking weighed about 40 psf and the new deck only weighs 18.3 psf, it was necessary to work from the center of the main span outward in order to avoid excessive uplift at the end anchorages. Then when work was ready to begin on the north truss the traffic was shifted to the sidewalk side and the north half of the roadway was completed on the suspended span from L18 to L18′. Thereafter work began on either side whichever was most expedient.

The reconstruction of the deck consisted of removing all of the old 10-in. simple I-beam and channel stringers and a 12-in. channel stringer and replacing them all with new 12-in. @ 31.8# continuous I-beam stringers as shown on Fig. 18. The new stringers were first supported on top of the old floor beams and then the floor beams themselves were built up around the stringers and reinforced with a new flange on top of the stringers as shown on Fig. 16.

The web of the new floor-beam tee-section top flange was first fillet welded to the web and back of the old top floor-beam flange angles, then connected to the webs of the new stringers with new splice plates that were first butt welded to the stringer web and then fillet welded to the web of the new tee.

This drawing also shows the stringer splices, the deck and the new steel curb and the new bottom laterals in cutaway details. The new top flange for the floor beam is only a 5- x $^3/_4$-in. plate and the web $^5/_{16}$ in., but since it deepens these old floor beams from 36 to 48 in. it also strengthens them from H10.6 at 18,000 psi to H20-S16 at only 15,100 psi. The new web plates also extend in

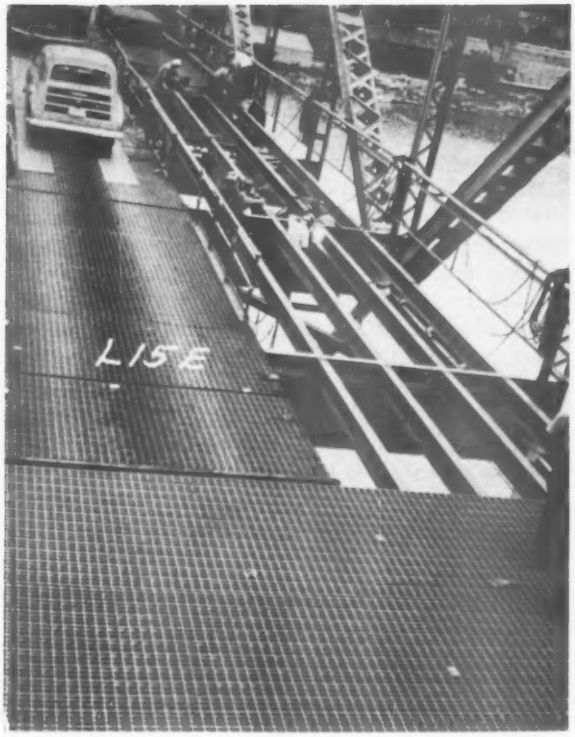

Fig. 18 The new stringers and floor beams on the main spans

between the hanger at the ends for direct vertical support.

Figure 19 shows a group of welders rebuilding one of these floor beams while two others are splicing the stringers.

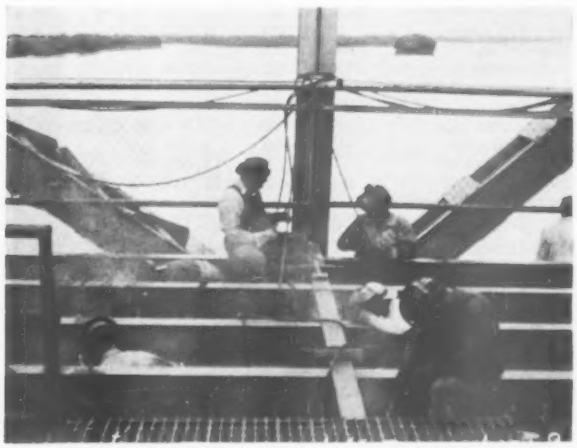

Fig. 19 The reconstruction of a floor beam

Figure 20 shows the completion of the deck on the bridge as of June 29, 1953 on the 175-ft span where the temporary pieces of the decking were butt welded back together again and used over each floor beam with full width pieces in between. The traffic is passing on the south side of the roadway and a battery of seven of the welding machines are on the sidewalk. The new interlocking welded plate expansion joint at Pier 5 is shown in the foreground.

Fig. 20 The completion of the new deck

Other details consisted of the addition of new double-plane rigid cross bracing in all portals and the complete new bottom lateral system that can be seen in Fig. 4. These members were all made of 6H @ 15# beams bracketed out to the depths of the truss members by welding as shown in Figure 16 and all field connections were welded. These members are not only effective in themselves but they also support the old members so as to make them more effective.

In this manner this bridge was strengthened so that now it does not weave and vibrate anymore and feels sturdy under the heaviest trucks. Nothing was ever taken away and the existing members were greatly strengthened by welding.

The quantities involved and the contract cost of this work were as follows:

1.	5-in. I-beam Lok flooring, 53,729.87 sq ft @ $5.00		=	$268,649.35
2.	1 1/4-in. sidewalk grating, 12,236 sq ft @ $6.00		=	73,416.00
3.	New steel curb, 91,973 lb @	$0.40	=	36,789.20
4.	New metalwork, 647,200 lb @	0.45	=	291,240.00
5.	Reset old metalwork, 230,605 lb @	0.50	=	115,302.00
6.	Removal of timber deck, lump sum		=	20,000.00
7.	Miscellaneous extra work and approaches		=	27,477.60
	Total Contract Cost			$832,874.15

The equipment involved included two cranes, two trucks, three compressors and 19 welding machines plus miscellaneous other small tools, jacks and equipment.

The actual field work began at the site on Nov. 20, 1952 and was completed on Aug. 21, 1953, including the painting. It required 60,370 man-hours of time on the bridge site to do the work including the painting. The labor was classified as follows in Table 1.

From this it can be seen that the welders pay is the same as for any other iron worker in the Burlington District and while any qualified welder is a good iron worker it does not follow that any iron worker can weld and, had the local union permitted, the contractor would have gladly paid a premium for qualified welders.

All men who were permitted to do welding on this project were first qualified rigidly in accordance with

TABLE 1

The Approximate Field Labor Costs—Nov. 20, 1952 to Aug. 19, 1953

Classification	*Man-hours*	*Rate*	*Cost*
Superintendent	1,239	$3.82	$ 4,722.98
Engineer	1,663	3.82	6,352.66
Carpenter foreman	872	3.82	3,331.04
Carpenters	2,211	2.72	4,856.21
Iron-worker foreman	4,916	2.845	13,986.04
Crane operator	1,871	2.70	5,051.70
Welder operator	2,731	2.175	5,938.93
Compressor operator	1,636	2.175	4,217.55
Oiler driver	1,863	2.175	4,050.80
Welders	7,979	2.595	20,695.51
Iron workers	19,597	2.5925	50,854.21
Truck driver	1,360	1.95	2,602.00
Tool laborer	545	1.84	1,002.80
Watchmen	2,080	1.00	2,080.00
Flagmen	564	1.00	564.00
Common labor	5,411	1.69	9,145.59
Cement finishers	80	2.22	177.60
Paint superintendent	657	6.00*	3,942.00
Paint foreman	657	5.00*	3,285.00
Painters	2,529	4.55*	11,506.95
	60,371		$158,363.57
12.5% insurance on labor			19,795.45
			$178,159.02

* Includes 19 hr. of overtime pay per week.

the Standards of the AMERICAN WELDING SOCIETY by the Robert W. Hunt Co. inspector of the project. The test specimens were welded at the site in the horizontal, vertical and overhead positions from pieces of steel that were taken from the bridge in sample welds about 6 in. long. These samples were then machined smooth, cut to size and tested at the Murrary Iron Works in Burlington.

In all, 32 men applied for the welding qualification tests and only 10 men failed to pass. Of the rest the following 18 men were qualified for groove and fillet welding in all positions: Marion Howe, Thomas Howe, G. Gerst, Paul Mathismeier, Emil Braun, R. E. Brown, Earl Parrich, Glenn Parrich, Robert R. Hasty, Kenneth Armstrong, Nelson C. Davis, Herbert Smith, Donovan Thorpe, Ronald Wilson, Jake Myers, Lyle Hinman, LaVerne Behsman and Dale C. Wilson.

The other four welders were qualified for fillet welding only, but in all positions as required for the decking and other lesser important parts. They were Eugene Martin, Clifford Ayers, Richard Kerr and Paul F. Hester.

The samples of old steel that were sent in for chemical analysis and other physical tests were found to be of excellent quality for welding. They averaged only 0.20 carbon, 0.32 manganese, 0.008 phosphorus and 0.036% sulfur, with a yield point of 38,400 psi, and ultimate strength of 59,200 psi and about 27% elongation as manufactured in 1916.

Corresponding to this the new steel made in 1952 averaged 0.235% carbon, 0.507 manganese, 0.012 phosphorus and 0.035 sulfur, with a yield point of 42,500 psi, an ultimate strength of 66,850 psi and 27.4% elongation for an average of 25 samplings.

Both the old and the new steels also behaved satisfactorily on the 180-deg x $\frac{1}{2}$T cold-bend tests. In regard to quality control the only other test that the author would like to see reinstated would be an impact test, similar to the Charpy Izod impact tests, to eliminate the rotten and notch-sensitive steels that will otherwise pass the standard certified mill tests.

The higher yield point of the more modern steel is very desirable. It would also be desirable to make our modern steel more rust resistant and to raise the yield point of our mild carbon steels by a limited amount of cold working, at the expense of a lesser and a more reasonable amount of elongation in order to lessen the probability of brittle fracture under biaxial and triaxial stress concentrations that are sometimes caused by welding.

The following table of traffic on the bridge for the years 1951, 1952 and 1953 as measured by the various classifications of tolls that were paid for during these years attests the volume of traffic that was handled during this reconstruction and the efficiency of the process.

Traffic Data—MacArthur Bridge, Burlington, Iowa

	1951	*1952*	*1953*
Automobiles	741,133	824,325	793,967
Light trucks	90,895	96,244	90,420
Heavy trucks	35,343	37,610	37,267
Charge trucks	36,527	33,091	38,571
Miscellaneous walkers	12,675	11,050	4,050
Cash busses	771	612	568
Return trip fares	426,155	492,653	468,612
Total Fares	1,343,499	1,495,869	1,433,455
	Income		
Gross tolls	$277,202.21	$327,305.73	$332,395.71
	Operating Expenses		
Toll Collectors' Salaries	$34,542.34	$31,920.13	$35,098.47
Illinois Taxes	9,587.00	9,312.72	9,672.72
Repairs and Material	18,944.63	213.73	279.88
Engineering & Plans	3,640.00	6,342.84	20,091.22
Lighting	657.40	1,142.35	665.64
Insurance	266.92	8,011.09	19,876.97
Miscellaneous	2,409.96	4,238.24	1,816.35
Bond Principal	...	15,000.00	20,000.00
Bond Interest	...	11,012.50	19,090.00
Bond Legal Expense	...	...	600.00
Total Expenses	$70,048.25	$87,193.60	$127,191.25
NET INCOME	$207,153.96	$240,112.13	$205,204.46

From this data we find that an average of 4000 vehicles per day paid an average toll of 22 cents per vehicle to cross this bridge during the construction period in addition to the trucks and cranes and other pieces of construction equipment that were necessary for the work.

The gross tolls show that there was no loss of income during the reconstruction period and while they did not show as large an annual increase as might be expected in terms of the annual production of vehicles, the net annual income for 1953 was still larger than the entire initial cost of the bridge in 1916.

It is also interesting to compare the annual cost of financing these improvements to the annual maintenance costs that were expended in 1951 on materials and

repairs that were necessary to keep the old timber floor and handrails in service. There comes a time in the life of any old structure when it is more economical to replace it with a more modern improvement.

In conclusion bronze plaques with the following inscription were mounted on each end of the bridge in honor of those who were responsible for this outstanding work:

The design and plans for the work were made by the author and the work was carried out under the direction of Mark Baty and Donald R. Miller, Engineers, and Louis C. Barnett, Superintendent for Vogt and Conant and for whom John Cleary was a most able iron-worker foreman on the main span reinforcements.

An equivalent bridge would cost the City of Burlington about $3,500,000 if it were to be reconstructed new today.

MacARTHUR BRIDGE
Rebuilt for the City of Burlington, Iowa
· 1953 ·
THOMAS J. SMITH, MAYOR
COUNCILMEN
Arthur A. Drebenstedt • Commissioner of Finance
Charles L. Zaiser • Commissioner of Public Safety
Harry Staff • Commissioner of Streets and Superintendent of the Bridge
Harry D. Hatt • Commissioner of Parks

Frederick M. Holsteen • City Solicitor
Harry McDermott • Chief Toll Collector
Robert Schlampp • City Clerk

NED L. ASHTON, IOWA CITY, IOWA
CONSULTING ENGINEER
THE VOGT & CONANT CO., CLEVELAND, OHIO
GENERAL CONTRACTORS

Inspection Techniques for Quality Welding

Discussion by Jay Bland

The authors have presented a concise discussion of the various tests and techniques which are being used for the inspection of weldments. In general, they have managed to emphasize the more important aspects of each inspection method, and they have not failed to mention some of the limitations which frequently are ignored in the usual reviews of this nature.

Several of the statements made by the authors are of particular interest and should be noted. They decry the double standards of inspection by which the degree of inspection is predicated only on the importance of assuring that the standard is met. Although they recognize the economic conditions which produce this result, the authors note that there should be little difference in cost between sound, good quality welds and poor, inferior welds, since the same motions are necessary to obtain both.

The authors, probably by design, have not mentioned the role of welder's qualification in the over-all inspection picture. Certainly, it would seem that a well-developed and supervised welder's qualification (and requalification) program would go a long way toward assuring good quality welds, probably to a greater extent than would postweld inspections. It is true that governing codes and specifications determine the type and extent of inspection; however, these reflect the purchaser's desire to be assured of sound welds, an assurance for which he is willing to pay—up to a point, that is. The fabricator obviously must always keep down the costs of repairs which may be required as a result of such inspections, and his utilization of qualified procedures and of qualified welders probably influences greatly the extent of those repairs. The authors' comments in this matter would be of interest.

The authors conclude with a rather optimistic statement regarding a good inspector, who, with the full cooperation of those responsible for production, should have full and complete answers to the question: "How good is good enough?" Since the code and specification writing bodies are not themselves certain of how good is "good enough," I doubt that any inspector, of any degree of competence, could answer that question. However, the authors' preceding advice to welding inspectors is sound, and should be adopted where possible. With intelligent usage of available literature, including the present paper, it should not be too uncommon to find inspectors who can say "yes" when asked, "Is this weldment as good as the code (or specification) requires it to be?" The authors are well aware that even this assurance is enough responsibility for any inspector.

Authors Reply

The authors are gratified at the time taken by Jay Bland, a recognized authority on the subject, to discuss the various aspects of our paper.

Actually, since most of Mr. Bland's discussion is rather complimentary there is very little for the authors to use in the way of rebuttal. Only in one part of his discussion, where he mentions specifically that the authors have "by design" neglected to mention the role of the welding operator's qualification in the over-all inspection picture, should the authors offer an explana-

(*Continued on page 355*)

Jay Bland is Senior Project Engineer, Engineering Research Dept., Standard Oil Co. (Indiana), Whiting, Ind.

Paper by Lew Gilbert and William B. Bunn was published in THE WELDING JOURNAL, 31 (7), 614–619 (1953).

Resistance Spot Welding of Titanium and Its Alloys

Properties of spot-welded joints in Titanium and its alloys and comparisons with spot-welded joints in other materials

by A. J. Rosenberg

INTRODUCTION

IT IS the purpose of this paper to discuss the properties of resistance spot-welded joints in titanium and its alloys in terms of comparisons with spot-welded joints in other, better-known materials. With such information available, design engineers and manufacturing people can begin to think in terms of these relatively new materials and to seriously consider their adoption where the properties of high strength to weight ratios and excellent corrosive resistance makes their use attractive.

Selections of engineering metals, consciously or not, are made on the basis of comparisons. Thus, the designer wants a stronger material, or a lighter weight material or a more ductile one. Everything is evaluated from a specific frame of reference. This becomes even more apparent when a new group of materials, such as the titanium alloys, become available and comparisons with well-known engineering materials are painstakingly made. Not only are comparative strength and performance data necessary, but the metals reaction to fabricating processes such as welding must be studied. Resistance welding, perhaps more than any other welding process, requires comparative data for full understanding and usefulness because of the necessity for expressing strength levels in terms of total load to failure rather than as load per unit area.

The information contained in this paper was compiled in the Thomson Laboratory of the General Electric Co. as part of a materials investigation program. The obtaining of such Laboratory information is the first stage in preparing to use relatively new and unknown materials in production.

All spot welding to be discussed here was accomplished using conventional single-phase a-c press-type welding equipment rated at either 100 or 200 kva and equipped with synchronous thyratron control panels. Test coupons were approximately 1 in. wide and 4 to 5 in. long in various thicknesses. Weld evaluations were made by analysis of the results of cross-sectional studies, tensile shear, tensile pull-out and, in one instance, fatigue tests.

Table 1—Titanium Materials Investigated for This Report

Group	*Manufacturer*	*Manufacturer's Designation*
Commercially pure titanium	Titanium Metals	Ti-75A
	Rem-Cru	RC-55
Medium-strength titanium alloys	Titanium Metals	Ti-100A
	Rem-Cru	RC-70
High-strength titanium alloys	Rem-Cru	RC-130A

There are now at least eight different and distinct titanium alloys commercially available with strengths ranging from 75,000 to 175,000 psi. For the purpose of this investigation and discussion, it is convenient to group them into three broad categories. These include the commercially pure grade of material, the medium strength oxygen-nitrogen and carbon alloys, and the high-strength alloys with metallic additions. The electrical and thermal properties of all of these materials differ little from the stainless steels. Electrical resistivity and thermal conductivity of the commercially pure titanium is of the same magnitude as Type 302 stainless, although coefficients of expansion are somewhat lower for the titanium. Tests were limited to the five materials listed in Table 1, purchased from two major producers of titanium: Rem-Cru, Inc., and Titanium Metals Corp.

COMMERCIALLY PURE MATERIALS

Only the low-strength, unalloyed titanium usually prepared by melting high-grade sponge in water-cooled copper crucibles with no appreciable metallic or gaseous

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Presented at the National Fall Meeting, AWS Oct. 19-23, 1953, held in Cleveland, Ohio.

pickup or additions will be considered as commercially pure. Both RC-55 and Ti-75A fall into this category.

These materials possess nominal tensile strengths of 75,000 and nominal yield strengths of 55,000 psi with elongation values of over 30%. Rem-Cru, Inc., identifies its alloys with an RC prefix, followed by the number 55, designating nominal yield strength; Titanium Metals Corp. employs a Ti prefix, followed by the number 75, designating nominal ultimate tensile strength. Both manufacturers use this same system to describe their higher-strength materials.

The strength-to-weight ratio advantage of the commercially pure grades of titanium is offset to a large degree because of the high cost of the material. Thus, only cursory spot-weld tests were made on RC-55 and Ti-75A.

Because of the correlations between weld strength and weld diameters, General Electric, Thomson Laboratory practice has been to require specific "minimum" and "average" weld sizes and tensile shear strengths for spot welds dependent on parent material thickness and ultimate strength. (These requirements are well above those of the military.) For materials in the 70,000 to 150,000 psi ultimate tensile strength range, the tensile shear requirements for single-spot weld are tabulated in Table 2. Sound welds in titanium of equivalent size and strength were obtained for a wide range of current, force and time combinations and tensile shear strengths were comparable to those of spot welds in materials of comparable strengths. Failure in spot welds in 0.094-in. RC-55 and 0.060-in. Ti-75A took place at values well above the requirements listed in Table 2. Failures were of the "button" type, wherein the parent metal tore away from the weld and was, of course, a more desirable condition than a shear type failure which takes place through the weld along mating surfaces.

No difficulties were anticipated with these materials in the shop. The materials tested in the Laboratory, however, had uniformly clean surfaces which could be welded after simple wiping to remove oil. On several development assemblies made in the shop, scale which formed during annealing operations had to be removed to permit consistent welding. A light scale formed below 750° F was readily removed, but scale which formed above this temperature was extremely tenacious and required mechanical or special chemical treatments. Once their surfaces were made uniform, these alloys were welded satisfactorily. The Laboratory evaluation had helped to provide confidence in acquiring experience with these new metals and a starting point for shop welding procedures. Alloys of higher strengths, however, were needed to make substitutions of titanium more practical from an economic point of view.

Table 2—Thomson Laboratory Tensile Shear Requirements for Single-Spot Specimens

Material thickness (70,000–150,000 psi ultimate), in.	*Thomson laboratory load requirements, lb*		*Average load to failure, lb*	
	Minimum	*Average*	*RC-55*	*Ti-75A*
0.060	2200	2600	...	2700
0.094	4200	4960	5800	...

MEDIUM-STRENGTH ALLOYS

The oxygen-nitrogen and carbon titanium alloys, including RC-70 and Ti-100A, provide an increased strength level group without appreciable sacrifices in ductility. With nominal yield and ultimate strengths of 70,000 and 100,000 psi, respectively, these materials are naturally more attractive to the designer than the commercially pure grades. Initial spot-weld tests indicated that both RC-70 and Ti-100A could be joined as readily as the lower strength materials although the nature of the failure appeared to be one of lower ductility. In the hope of improving these results, effects of weld time were evaluated. Joints were made in these alloys at 3, 8, 12 and 20 cycles, respectively. Current was adjusted to maintain equivalent weld diameters, and force was held at a constant value. No difference was noted for either weld strength or type of failure for these four conditions, but the heat-affected zone did show the cooling effects of short weld times as illustrated in Fig. 1. The cross sections are for welds made at 12 and 8 cycles, respectively. The heat-affected zone in the 12-cycle spot has a normal, elliptical pattern; the weld made at 8 cycles shows an indented effect. At 3 cycles (not shown) this indentation is even more marked. Since failures occur around the edge of the weld in the heat-affected zone, there is some credence to the thought that short weld times are preferable. Since 3 cycles might be too low for consistent production results, 8 cycles were considered satisfactory and further studies were made employing this weld time.

When development parts were made of these low-alloy materials in the shop difficulty was experienced in

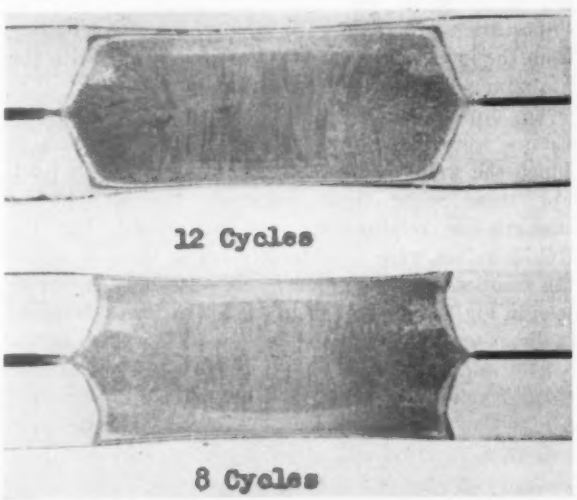

Fig. 1 Effects of time on spot-weld heat-affected areas RC-70 material. × 10

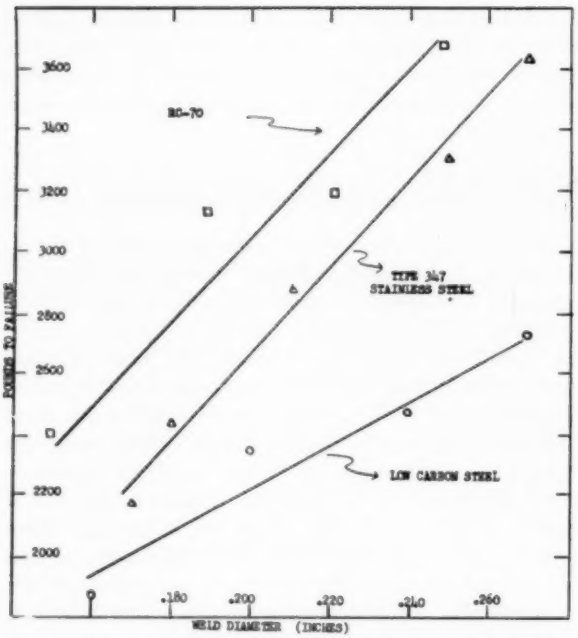

Fig. 2 Spot-weld tensile shear strength vs. spot-weld diameter (0.062-in. material)

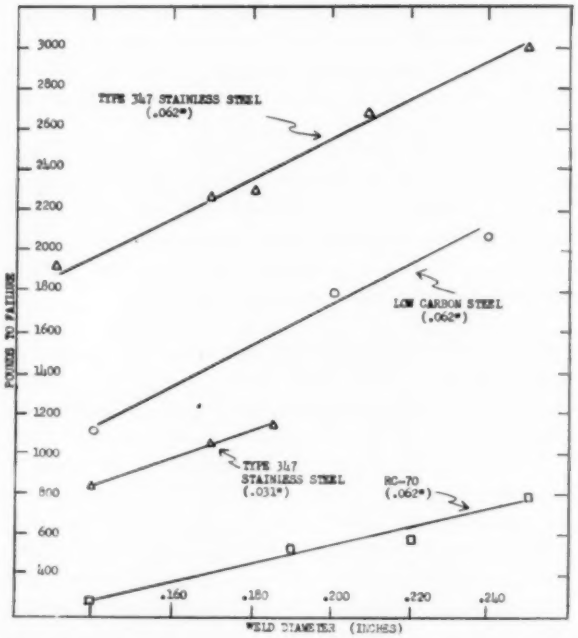

Fig. 3 Spot-weld tensile pull-out strength vs. spot-weld diameter

distinguishing between the actual weld diameter and the heat-affected zones apparent in Fig. 1. Extreme care must be exercised in the polishing, etching and illuminating techniques used to bring out these differences.

The effects of weld diameter on weld strengths are fairly well known for steel. Several tests were conducted to further establish this relationship for both Type 1020 and Type 347 steels. As might be expected, the tensile shear strengths of welds in these materials increases in essentially a straight-line fashion with weld size from the point of minimum consistent weld diameter to expulsion. For titanium this same relationship holds true. Figure 2 contains three curves of weld strength vs. weld size for welds made in 0.062-in. RC-70, AISI-347 and SAE-1020, respectively. The slopes are comparable with strength levels increasing from the low carbon to the stainless steel and with the titanium alloy possessing the highest values.

To obtain additional comparative data, similar studies were made for tensile pull-out specimens in which the weld is subjected to a straight tensile load. For these same three materials the straight-line strength-size relationship was maintained, but the RC-70 values were considerably below those of either the stainless or low-carbon steels. In fact, as can be seen in Fig. 3, 0.062-in. RC-70 failed at lower strengths in direct tension than 0.031-in. Type 347 welded joints.

The importance of low-tensile strength in itself is questionable since loading of spot welds is almost always one of shear. But pull-out values were not the only indication of lower-than-normal performance for these low-alloy grades.

Fatigue data were compiled for spot-welded joints in 0.094-in. Ti-100A. Weld times of 8 cycles were employed and current was adjusted to produce the weld diameter required by Thomson Laboratory instructions. Samples were subjected to cyclic loading with various static loads and curves of pounds to failure vs. cycles to failure (or stress-frequency) were obtained. Such a curve for a 500-lb steady state load is shown in Fig. 4. The value at 10,000,000 cycles is considered the endurance limit of the joint for the given static condition. But this information has little value in itself. A more complete picture can be obtained by plotting a diagram for several static and dynamic conditions at 10,000,000 cycles.* Figure 5 is such a curve showing alternating load to failure at 10,000,000 cycles for various steady loads. With zero alternating load the tensile shear strength of the spot-welded joint may be considered the static load required for failure. Yet, because these values are in pounds to failure, rather

* This might be considered a modified Gobdman-type diagram.

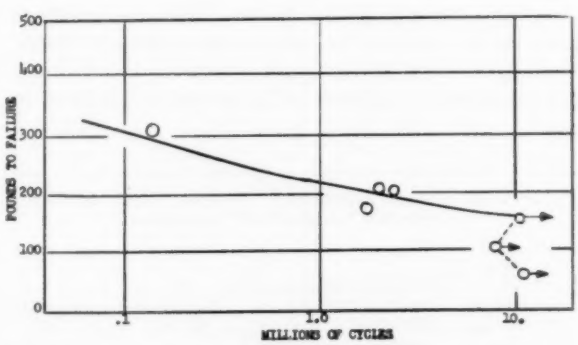

Fig. 4 Stress-frequency curve for single-spot weld in 0.094-in. Ti-100A (500-lb static load)

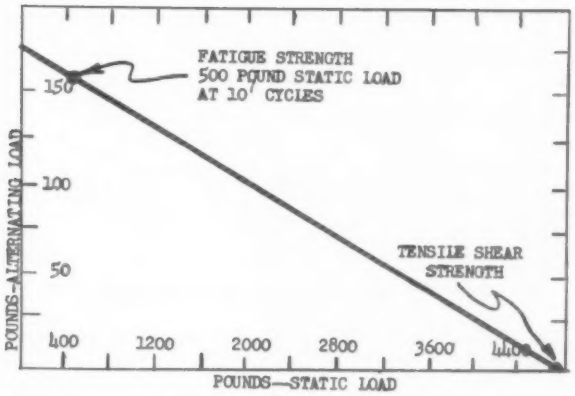

Fig. 5 Static load vs. dynamic load at 10,000,000 cycles (modified Goodman-type diagram) single spot in 0.94-in. Ti-100A

than pounds per unit area, interpretation is difficult and no direct comparisons with the parent material can be made. However, the slope of the curve in Fig. 5, or the ratio of fatigue strength with zero static load to tensile shear strength, can be used to compare spot welds in Ti-100A with welds in other materials. From Fig. 5, this ratio is less than 4%. For other structural materials which have been spot welded and fatigue tested, this ratio has ranged from 5.8% for low-carbon steel to over 10% for 24ST aluminum. The welds in titanium are significantly lower and this must be taken into account in design by location of spot welds in areas not subjected to fatigue stresses. By being aware of and recognizing these facts, design engineers have been able to overcome these disadvantages and both RC-70 and Ti-100A have been fabricated in development components involving spot welding with success.

HIGH-STRENGTH ALLOY MATERIALS

As with most metals, the higher the strengths which can be achieved, the more desirable the alloy. The grades of titanium containing metallic alloy additions and those which are generally considered high-strength alloys attain strength levels of 150,000 to 175,000 psi.

Fig. 6 Typical cross section (× 10) spot weld in RC-130A

Fig. 7 Low-ductility tensile shear failure for spot-welded joint in 0.060-in. RC-130A

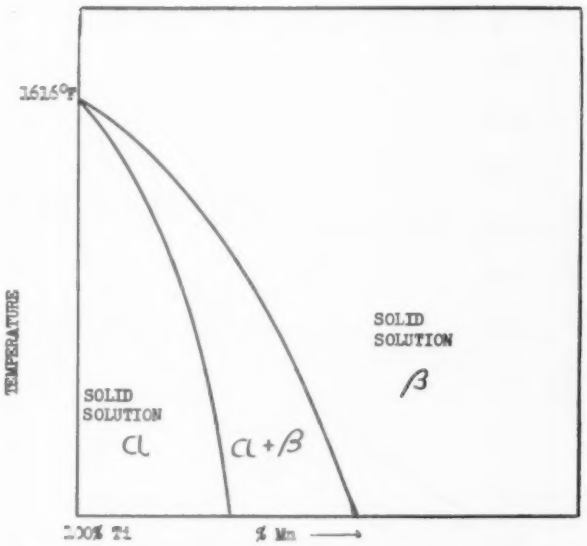

Fig. 8 Representative partial equilibrium diagram of Ti-Mn system

These include several ferro-chromium materials, and manganese, manganese-aluminum alloys. Of these only the 8% manganese RC-130A has been studied for spot welding characteristics. For this material, there is a drastic loss in ductility because of the rapid heating and cooling associated with welding. Initial testing of RC-130A indicated that while sound spot welds could be attained with a wide variety of machine settings, the weld failed abruptly in tensile shear tests with little or no plastic deformation. Figure 6 shows a typical cross section, while Fig. 7 illustrates the low ductility shear failures. Heat treatments performed on inert-arc welds, however, indicated a means for improving this brittle condition. While evaluation has not been entirely completed, enough improvement has been achieved to warrant discussion here.

"A typical equilibrium diagram for the Ti-Mn system is shown in Fig. 8. Above 1616° F, the material having no manganese consists of a single-phase beta, which is a body-centered cubic structure; below 1616° F the material transforms to a single-phase alpha hexagonal-close-packed structure. With increasing manganese content, the transformation temperature is decreased until a point is reached where the transformation is suppressed until the beta phase becomes stable at room temperature. Between these two extremes, a two-phase region of alpha and beta exists.

"At 8% manganese, the composition of RC-130A, the solid solution of beta transforms to an alpha-beta

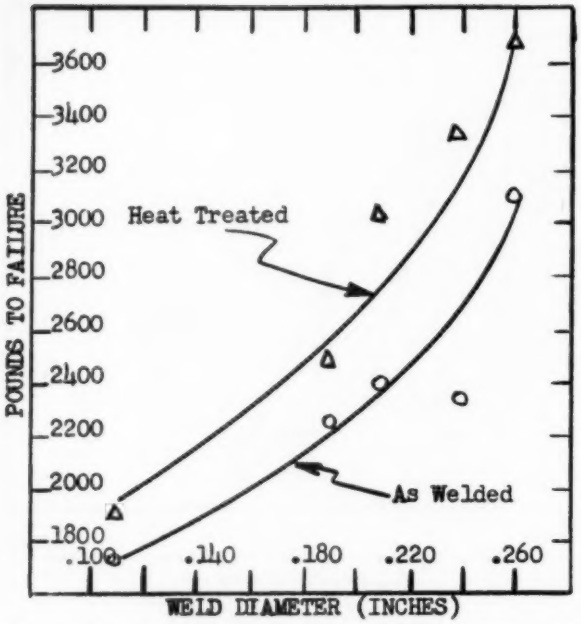

Fig. 9 Spot-weld tensile shear strength vs. spot-weld diameter for RC-130-A

structure upon cooling under conditions approaching equilibrium. In welding, however, the cooling rates are so rapid that an all-beta structure is retained at room temperature. This unstable structure is hard and brittle, so that it would be desirable to cause transformation to the stable alpha-plus-beta state after welding."*

In the "Restoration of Ductility in Alloy Titanium Welds",[1] a discussion of the isothermal transformation diagram of RC-130A indicated that an all-beta inert-arc-weld structure could be transformed in to an alpha-plus-beta structure with a subsequent increase in weld ductility through the use of isothermal heat treatments. Further, it was demonstrated that a slow furnace cool would also result in some transformation and improved weld properties. There was every reason to believe that a similar improvement could be attained for spot-welded RC-130A through such a heating cycle.

Test coupons of 0.048-in. RC-130A were spot welded at 8 cycles weld time with 1000 lb force and varying currents. Half of each group of samples were heat treated at 1500° F for 5 min and furnace cooled so as to cause partial transformation of the weld area. Tensile shear results and pull-out data were then compiled for both the as-welded and heat-treated specimens. Figures 9 and 10 summarize this information. The indications of improvements are clear, although further study on the effects of isothermal treatments are obviously necessary.

* This paragraph and the preceding one are taken from Reference 1.

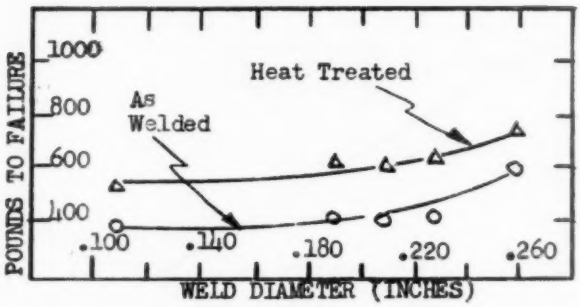

Fig. 10 Spot-weld tensile pull-out strength vs. spot-weld diameter for RC-130-A

These heat treatments, however, cause detrimental grain growth in the parent material, so that any means used to restrict heating to the immediate weld area would be beneficial. Toward this end, tests are planned on heat treatments in the welding machine. This latter method would offer maximum hope of practicability in restoring spot-weld properties although a problem may exist if the heat-affected areas cannot be improved.

While these results are highly encouraging, tests have not yet reached the point where the high-alloy material can be considered suitable for production parts involving spot welding. It is hoped, however, that an answer is in sight.

SUMMARY AND CONCLUSIONS

The commercially pure grade of titanium and the medium-strength alloy materials have shown themselves to be readily spot welded. Tensile shear strengths are equal to or greater than that of welds in equivalent thicknesses of austenitic stainless steels. Direct tensile strength and fatigue levels are somewhat low and these facts must be taken into account in designing welded parts. The high-strength alloys are most attractive but lowered ductility after welding has hampered their widespread adoption. Heat treatments may restore a great deal of the properties but tests are not yet complete.

It is hoped that the findings reported will stimulate interest in these alloys; that the way toward further study has been indicated, and that hope has been held out for the design engineers who have wanted to use titanium but who were hesitant about its unknown qualities. Wide personal experience with titanium must be obtained to assure the confidence necessary for large-scale adoption of these materials.

Reference

1. Report by E. F. Hutchinson, S. Weiss and A. J. Rosenberg presented at the AWS Spring Meeting at Houston, Tex., June 16, 1953. Published in the August 1953 issue of the Welding Journal.

Welding of 90/10 Copper-Nickel Alloy

Suitable procedures for welding 90/10 Cupro-nickel alloys. Preferred weld composition and shielding gas and flux requirements

by G. R. Pease and T. E. Kihlgren

Abstract

Data are presented which indicate that iron-bearing 90/10 cupro-nickel can be satisfactorily welded by all of the currently important fusion welding processes. The important variables are defined and suggested areas of usefulness are outlined for each of the several methods. Data include preferred weld composition, the effect of composition on strength and soundness, appropriate filler wire composition and shielding gas and flux requirements. The response to silver brazing methods is also treated briefly.

INTRODUCTION

WITHIN the past few years an iron-modified 90/10 copper-nickel alloy has been made available to fabricators for constructing condensers and piping and for use in other areas where resistance is required to the destructive action of rapidly moving salt water. Corrosion rates have been established[1–3] and extensive metallographic studies completed[4] but relatively little attention has been paid to the weldability of the alloy.

The recent critical shortage of nickel served to focus attention on this new alloy as a substitute for 70/30 copper nickel in the shipbuilding industry and prompted the Bureau of Ships, a few years ago, to initiate sufficient research at the International Nickel Co. Research Laboratory to define the weldability of the 90/10 alloy by all of the currently important welding methods. This paper presents the findings of a test program which stemmed from this origin and which was completed under the provisions of Bureau of Ships Contract No. Nobs 54688.

During the course of the investigation the work of Hawthorne[5] on inert-gas-shielded arc welding of the 90/10 alloy was published, but detailed information in the literature concerning other joining methods remained scarce.

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SCOPE OF STUDY

The following fusion welding methods were included in the study:

1. Flux-shielded metal arc (coated electrodes).
2. Inert-gas-shielded tungsten arc.
3. Inert-gas-shielded metal arc.
4. Oxy-acetylene.
5. Submerged arc.

In addition, there was included a partial evaluation of the response of the alloy to conventional silver brazing procedures. From the start of the investigation an obvious requirement was a coated electrode of suitable composition. Electrodes with 70/30 cupro-nickel core wires are available and have been available for some time, and data in this paper show that they are capable of making good joints in the 90/10 alloy. However there was need for an electrode of matching composition.

Investigation of both of the inert-gas-shielded arc-welding processes involved, primarily, the definition of an appropriately fortified filler wire composition. In addition, optimum conditions were established for welding light gage material where filler wire is not customarily added. A limited amount of work was also done with the oxy-acetylene and the submerged arc processes.

MATERIAL AND EQUIPMENT

Substantially all of the plate and sheet material used in the test program was rolled from a single heat (No. 853) of commercially produced low phosphorus 90/10 alloy.

Phosphorus was specified as low and not permitted as a deoxidizer on the basis of some unpublished contemporary work on related alloys, which demonstrated quite clearly that its presence is detrimental to weldability. It was also recognized that the iron content of the alloy was a potentially important variable, but so many other factors had to be considered that initially, at least, it seemed advisable to eliminate the base metal iron content as a variable and to conduct all tests on a single heat of plate and sheet material. However, since the iron content which was selected (1.5%) was on the high side of the specification range,

Table 1—Composition of Plate, Sheet, Tubing and "Unalloyed" Filler Metal

	Plate and sheet (Ht No. 853)	*Tubing*	*"Unalloyed" filler metal*	*Spec. MIL-C-15726 (Ships)*
Cu	87.43	88.06	87.91	*
Ni	10.12	10.02	10.10	9.0 –11.0
Fe	1.45	1.37	1.53	1.00–1.75
Mn	0.53	0.38	0.38	0.75 max
S	0.002	0.005	0.002	...
Pb	0.006	0.001	0.002	0.05 max
Si	0.006	0.004	...	...
P	0.003	...	...	...
Mg	0.051	...	...	...
Zn	0.1	...	...	1.00 max

* Cu plus sum of named elements to be 99.50% min.

it seemed certain that any adverse iron effects could be readily detected and, if necessary, further defined by additional tests at other iron levels.

The composition of the plate and sheet material is shown in Table 1 and some selected physical properties, including values for the elastic modulus and fatigue strength, are shown in Table 2. In addition to the analyses shown in Table 1, spectrographic determinations were made for the presence of other residual elements and certain of the so-called tramp elements with the following results:

Traces present: Ag, Sn
Absent: Sb, As, Bi, Cd, Ti, V, Te

Material was supplied in the form of 1-, $^3/_8$-, $^1/_4$- and $^1/_8$-thick hot-rolled plate and 0.062- x 3-in. cold-rolled and annealed strip.

Bar stock, suitable for reduction to filler wire, and hard drawn tubing, both of commercial quality, were also obtained to supplement the stock of plate and sheet material. The compositions are included in Table 1. In addition to the wire which was obtained from the bar of nominal or "unalloyed" 90/10 composition, various laboratory heats of filler metal were prepared and tested as the need became apparent for improvement of weld metal quality and strength.

In line with the intent of this investigation to measure the response of the alloy to the commonly encountered welding processes, and with only a few exceptions, the test equipment and experimental procedures were conventional, in terms of current shop practices.

All of the experimental filler wires were produced from 30-lb laboratory heats of virgin metal, melted by high-frequency induced current in magnesia lined crucibles. The ingots were reduced to wire in the laboratory by hot and cold reduction to the desired sizes.

For the flux coating of bare wire, a small-scale laboratory extrusion press was used which is capable of simulating production equipment in most of the important details. Test welds were made with standard welding equipment powered by either a 300- or a 600-amp motor-driver d-c generator or a 200-amp selenium rectifier. No welding tests were attempted with alternating current. Inert-gas tungsten-arc welds were made with a 200-amp capacity manual welding torch. An Aircomatic Model 3 unit was used for the inert-gas consumable electrode process. Submerged arc welding was done with a Westinghouse Weldomatic unit modified to accommodate laboratory requirements for flexibility of use. Fatigue tests were conducted on a battery of R. R. Moore rotating beam machines operating at either 1750 or 3500 rpm. Modulus determinations were made on standard 0.505-in. diam. tensile bars, with elongation measured with a Ewing extensometer.

Data for all-weld-metal composition were obtained from $^1/_2$-in. high weld pads prepared in accordance with the requirements of current AWS-ASTM filler metal specifications. The Navy long-gage flat tensile bar was used to derive yield and ultimate strength data.

Welding tests included the preparation and testing of 10-in. long butt joints in plate of various thicknesses for the determination of X-ray quality and for physical property measurements. In evaluating coated electrodes, simple, downhand burn-off tests by an experienced test welder were sufficient to screen out the less desirable formulations from the more promising ones. The final criterion for good operability was the bead appearance and the ease of manipulation in a vertical fillet weld, made welding bottom to top. Resistance to weld hot cracking was measured where necessary, with an X-weld crack test specimen prepared and sectioned as shown in Fig. 1. A more complete description of the X-weld crack test specimen and its method of preparation are available elsewhere.[6]

Table 2—Physical Properties of Unwelded 90/10 Plate

Plate thickness (Ht No. 853), in.	*Condition*	*Rock "B" hardness*	*Yield strength (0.5% extension), psi*	*Ultimate strength, psi*	*Modulus of elasticity, psi × 10^{-6}*	*Fatigue strength*—Smooth bar*	*Fatigue strength*—Notched bar†*
1	As-rolled	58	35,600	53,500	20.6	...	...
	Annealed, 1400° F/$^1/_2$ hr	46	19,300	48,200	18.6	...	...
$^3/_8$	As-rolled	58	40,200	53,100	...	24,000	9,000
	Annealed, 1400° F/$^1/_2$ hr	46	20,300	48,100	...	20,000	14,000
	Solution treated‡	31	14,000	41,700	...	16,000	12,000
$^1/_4$	As-rolled	...	45,300	53,500	...	...	...
	Annealed, 1400° F/$^1/_2$ hr	...	21,700	48,100	...	...	...
$^1/_8$	As-rolled	...	30,900	52,200	...	...	...
	Annealed, 1400° F/$^1/_2$ hr	...	21,400	49,600	...	...	...

* 50,000,000 cycles.
† 0.020 in. deep V-notch, 0.010 in. root radius.
‡ 1 hour at 1650° F—water quench.

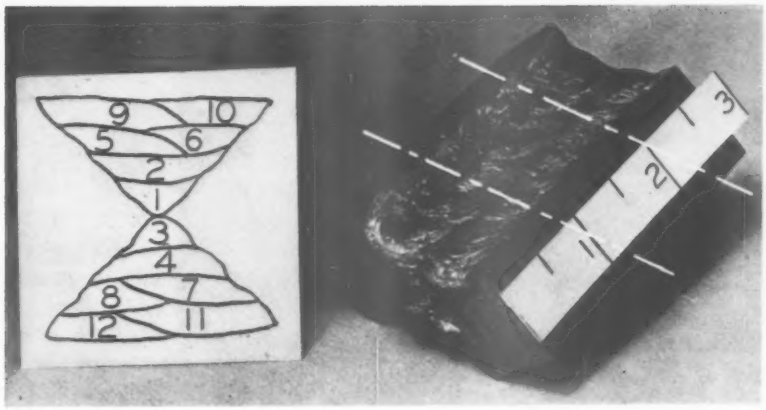


Fig. 1 X-weld crack test specimen

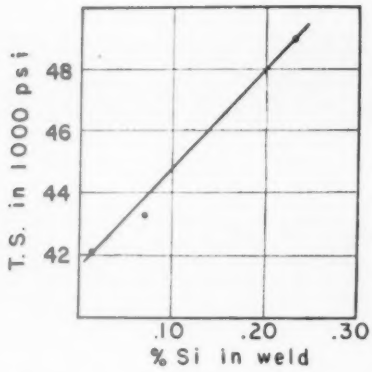


Fig. 2 Tensile strength vs. silicon content of 90/10 arc welds

METAL ARC WELDING

As mentioned previously, strong, ductile welds can be made in the 90/10 alloy with 70/30 cupro-nickel welding electrodes. Typical transverse properties are shown in Table 3, for a joint in $^3/_8$-in. thick, hot-rolled 90/10 plate, welded in the flat position with a commercially available 70/30 electrode.

Table 3—Transverse Joint Properties of 90/10 Plate Welded with 70/30 Electrode

Yield strength (0.5% ext.), psi	31,000
Ultimate strength, psi	49,100
Joint efficiency, %	100*
Guided-bend test:	
Face, deg	180, OK
Root, deg	180, OK
Free-bend test:	
Face, %	38, no failure
Root, %	36, no failure

* Specimens failed at weld-plate interface.

In deriving a 90/10 electrode of equal suitability it quickly became apparent that the two alloys were sufficiently different to require different flux coatings for optimum welding behavior. After examining a number of possibilities a silicate bonded coating based on approximately equal quantities of limestone, fluorspar, cryolite and titania, with a small amount of ferromanganese added for deoxidation, appeared to be optimum for the 90/10 alloy and ultimately became the preferred coating. However, welds were prone to be porous when this coating was applied to "unalloyed" core wire and the need became apparent for supplemental deoxidation. Both silicon and titanium were added to the coating and both were effective in reducing porosity, but they also tended to disturb the arcing characteristics or to impair slag removal, or both, so that it became necessary to make all or most of the required deoxidizer addition by means of a modified core wire. Small amounts of silicon could be tolerated in the coating, but, in general, not enough to be 100% effective.

Of a group of experimental wires containing silicon, titanium and also aluminum which, incidentally, seemed to cause "worm-holing," only the silicon-modified wires eliminated porosity without impairing electrode operability. Even small amounts of titanium seemed to cause repeated minor arc explosions. Silicon was additionally attractive as an alloying addition because of its potent effect in strengthening 90/10 weld metal (Fig. 2) and became the preferred core wire modifier. A minimum of about 0.20% was required in the core wire to be effective either as a strengthener or as a soundness improver and 0.40% appeared to be optimum.

Table 4—Transverse Joint Properties of 90/10 Plate Welded with 90/10 Electrode

	—Welding position—	
	Flat	*Vertical*
Yield strength (0.5% ext.), psi	26,800	24,400
Ultimate strength, psi	45,200	45,100
Joint efficiency, %	92	92
Guided-bend test:		
Face, deg	180, OK	180, OK
Root, deg	180, OK	180, OK
Free-bend test:		
Face, %	59	60
Root, %	35	62
Weld hardness (Rockwell "B")	39–50	37–52

Typical joint properties are shown in Table 4 and the level of radiographic quality indicated in Fig. 3 for an electrode consisting of a 0.43% silicon core wire, flux coated with the preferred limestone-fluorspar-cryolite-titania composition. The indicated properties are based on test joints made in $^3/_8$-in. hot-rolled plate using $^1/_8$-in. electrode in both the flat and vertical positions. Typical all-weld-metal analyses are shown in Table 5 for the same electrode containing core wire at two silicon levels. It is readily apparently that silicon losses are high and that, although only small amounts are needed for added strength, provision must be made for the losses by using relatively high silicon content core wires.

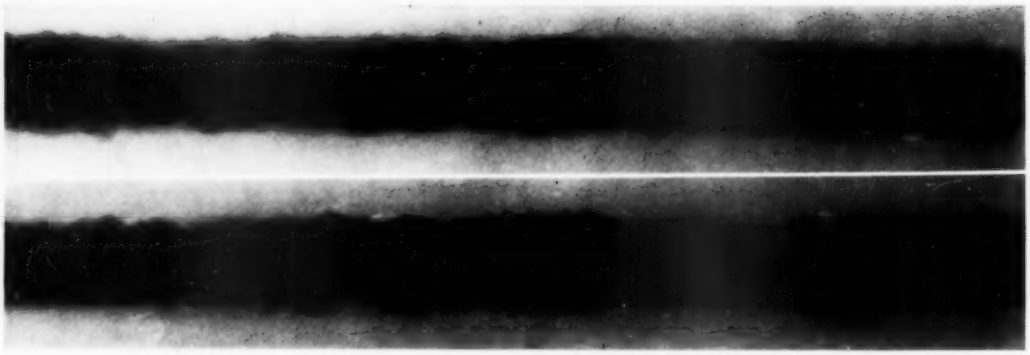


Fig. 3 Radiographic quality of metal arc welds made with coated 90/10 electrode

Table 5—Composition of All-Weld Metal Samples Deposited with 1/8-In. Coated Electrode

	Ni	*Fe*	*Mn*	*Si*
Wire A:				
Wire	10.07	1.53	0.49	0.43
Weld	10.04	1.73	0.87	0.10
Wire B:				
Wire	10.27	1.54	0.49	0.23
Weld	10.40	1.74	0.64	0.04

Lead-Silicon Relationship

Up to this point, all of the 90/10 alloy used either as plate or filler metal contained no more than about 0.005% lead or only one-tenth of that permitted by existing specifications. Since it is known that lead and silicon sometimes act synergistically to produce hot cracking in copper-base alloys, the question arose as to whether or not the same might be true of 90/10 welds. It therefore became necessary (if silicon were to become the preferred alloying addition) to re-examine the permissible lead content in silicon-containing welds and if necessary re-establish safe lead limits for filler wire.

To this end, a number of electrodes were coated with the preferred flux coating to which controlled amounts of lead and nickel-silicon were added, supplementing the silicon in some cases by the use of high-silicon core wires. A series of X-weld crack test specimens were then prepared and evaluated and the results used to develop the data plotted in Fig. 4. In these welds, the nominal iron, nickel and manganese contents were essentially the same as those shown in Table 5 with the lead and silicon values determined on chips machined from each X-weld specimen.

According to these results, if the 0.05% maximum lead level that is now recognized in base metal specifications must, for manufacturing reasons, be carried over into filler metal specifications, not more than about 0.15% silicon can safely be added to 90/10 weld metal If lead can be held to 0.02%, the permissible silicon content can be doubled, with modest improvements in strength properties, and at 0.01% lead the silicon content can approach a maximum of about 0.40%. These considerations apply, for the most part, to welds made under heavy restraint, as in the welding of rigid structural members or heavy gage material. In light gage welding more latitude can probably be tolerated.

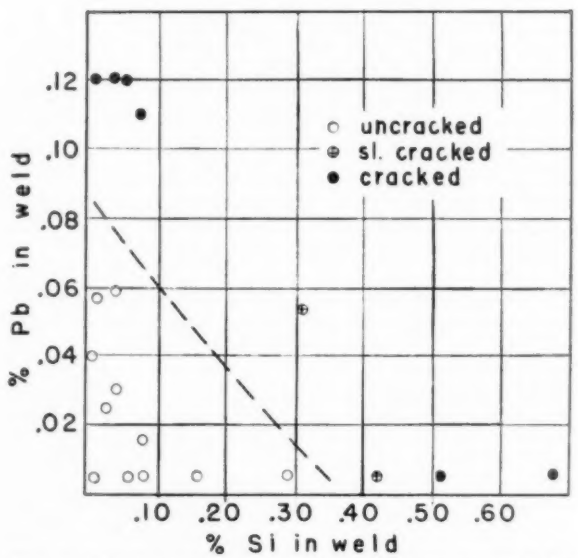


Fig. 4 Effect of co-present lead and silicon on weld hot cracking

Iron Precipitation

From the start of the investigation, one of the threats to the successful welding of iron bearing 90/10 cupronickel was the possibility of iron precipitation, either in the weld or in the weld heat-affected zone, with attendant losses of ductility in one form or another. The fears were, however, groundless. The X-welds of Fig. 4, for example, all contained normally expected iron contents of the order of 1 3/4%, and resistance to weld hot cracking was completely satisfactory, assuming adequate control of lead and silicon.

An additional series of tests at comparable iron levels served to indicate that there is likewise no loss of room temperature ductility, even after deliberate exposures of welded joints to temperatures within the

Table 6—Ductility of Metal Arc Welds Reheated to Indicated Temperatures

Condition	*% elongation in free bend*
As-welded	66, no failure
2 hr, 900° F	74, no failure
2 hr, 1000° F	67, no failure
2 hr, 1100° F	61, no failure
2 hr, 1650° F, water quenched	60, no failure

iron precipitation range. In this series of tests, the results of which are shown in Table 6, a number of $^{3}/_{4}$-in. wide transverse face bend specimens were prepared from a single welded joint made in $^{3}/_{8}$-in. plate with $^{5}/_{32}$-in. electrode. Weld elongation was measured on each specimen after exposure, in air, to the indicated test temperatures. It is apparent that no loss of ductility or other deterioration was experienced as a result of the several 2-hr exposures.

INERT-GAS-SHIELDED TUNGSTEN-ARC WELDS

The 90/10 alloy can be readily inert-gas welded with a tungsten electrode, either with or without a filler wire but weld quality is less sensitive to variations in welding conditions when the application is such that a suitable filler metal can be added. There are applications, however, involving light gage sheet, welded automatically or semiautomatically where it is the practice to melt down a standing edge or to weld a tight butt joint with no added metal. This latter situation was simulated and appropriate welding conditions defined in a series of 6-in. long butt joints in 0.062-in. thick sheet welded with the torch mounted on a motor-driven travel carriage.

In general, weld quality became poorer as the arc length and welding speed increased. For a given arc length and welding speed, however, weld quality was consistently better with helium than with argon. Welding under helium, there was no porosity in test welds made at speeds up to 60 ipm and with arc lengths up to 0.10 in. With a very short arc (i.e., 0.030 in.) and slow speeds, welds under argon approached freedom from porosity but with longer arcs and faster speeds all test welds contained considerable fine porosity. In most cases the gas holes were very small, so small in fact that they escaped radiographic detection, and close examination of a polished and etched surface was required to reveal their presence. It is believed, nevertheless, that the porosity observed was of a type and magnitude that could be troublesome in service.

As is the case with other metals, penetration of the 90/10 sheet was greater when welding under helium than when welding under argon. For instance, 0.062-in. sheet welded at 60 ipm required 180–200 amp for complete penetration under argon but only 150 amp under helium.

Vee-grooved butt joints in $^{1}/_{4}$-in. plate, welded manually using "unalloyed" 90/10 filler wire, were porous, with either helium or argon as the shielding gas, and the need was indicated for fortification of the filler wire. In manual welding, the arc is comparatively long, or at least variable, and the gaseous protection at times presumably less than perfect. It is probably for these reasons that manual welds were found to be more prone toward porosity than machine welds.

Filler Wire

In any event, based on observations of coated electrode behavior, silicon and titanium both appeared

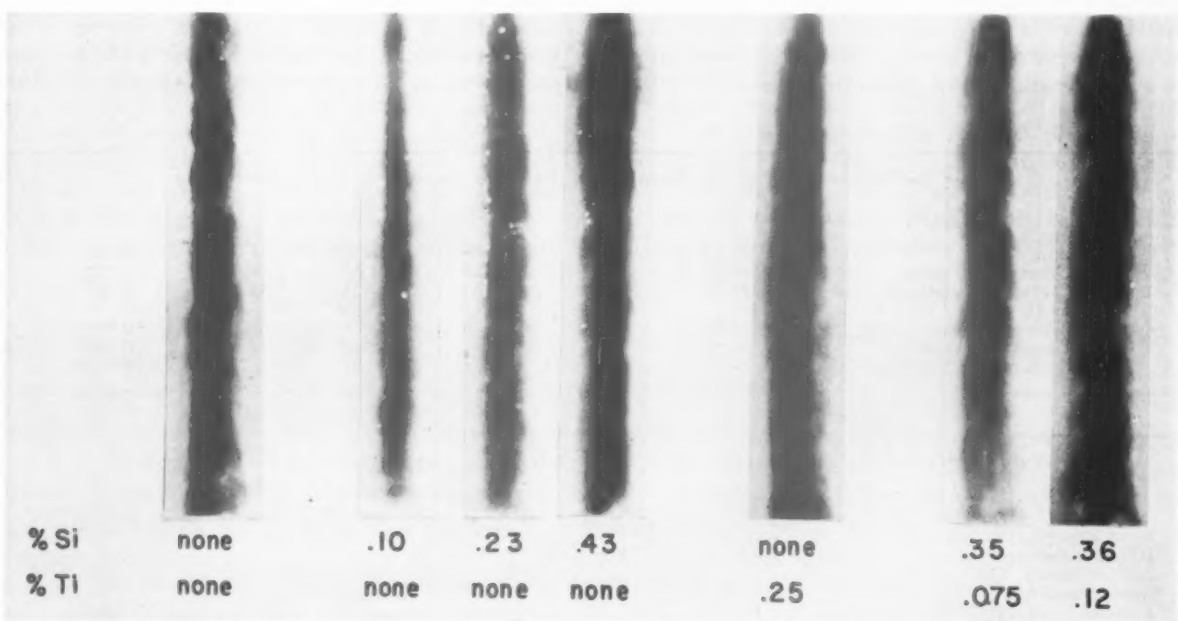


Fig. 5 Effect of silicon and titanium content of filler wire on quality of inert-gas tungsten-arc welds

likely to be beneficial under inert gas and a series of tests were conducted with filler wires containing silicon alone, titanium alone and others containing various combinations of the two. Specific benefits were readily demonstrated for each element but a combination of the two appeared to be necessary for optimum performance.

Silicon responded as expected with a weld strengthening effect but there was little or no improvement in weld soundness. Titanium, on the other hand, markedly reduced porosity with as little as 0.07% present in the wire (Fig. 5) but added relatively little to the weld strength at this level. It followed that a combination of the two elements was required for strong, pore-free welds and the specification shown in Table 7 took form. In this specification, the nickel, iron and manganese levels are established by alloy definition rather than by welding requirements.

Table 7—Filler Wire Composition for Inert-Gas-Shielded Arc Welding

Element	*Composition, %*
Nickel	9.00–11.00
Iron	1.00– 1.75
Manganese	0.25– 0.75
Silicon	0.20– 0.40
Titanium	0.05– 0.20
Magnesium	0.05 max
Lead	0.01 max
Sulfur	0.01 max
Other metals	0.50 max

Transfer to the weld is complete in the case of iron and nickel. The transfer of manganese across the arc is somewhat less than complete, at about 90%, but the 10% which is lost assumes no practical importance since present specifications call for no minimum manganese content.

The silicon limits are based on what appears to be a recovery of about 85%. According to the data for metal arc welds (Figs. 2 and 4), 0.20–0.40% of silicon in the filler wire will insure a substantial contribution to weld strength without jeopardizing the resistance to weld hot cracking. The 0.01% maximum lead content is keyed to the previously demonstrated lead-silicon relationship and based on the assumption that weld metal silicon contents might run as high as 0.30–0.35% if a 0.40% silicon filler wire were used in a joint where dilution by plate was at a minimum. The sulfur limit is arbitrarily set at 0.01% and may be unduly restrictive. The sulfur hazard is so well recognized, however, that it is believed desirable to meet this limit until experience, or further test results, indicate that relaxation is possible. The 0.05% maximum magnesium specification is also an arbitrary one permitting an addition, at the producer's option, if deemed necessary or desirable for better handling in mill operations. Its presence also provides a limited measure of insurance against trouble from incidental sulfur pickup.

Titanium was found to be a potent crack promoter but, fortunately, only at levels well above those needed to eliminate weld porosity. The threshold limit for titanium in the filler wire is determined both by the process and the welding conditions. Titanium losses are lower in consumable electrode than in tungsten arc welding, and this must be considered in seeking the commercially desirable solution of a single wire composition for both processes. It is expedient to keep the weld titanium content below about 0.15% so that resistance to weld hot cracking will be completely satisfactory under the most severe conditions of welding stresses, and above about 0.03% to insure freedom from weld porosity. A filler wire containing 0.05 to 0.20% of titanium will meet the above conditions using either the tungsten arc or consumable electrode processes. Obviously, where welding stresses are moderate or low, or plate dilutions are high, greater latitude exists with respect to weld and filler wire titanium contents.

All-weld-metal analyses are shown in Table 8 for metal deposited with $^1/_8$-in. diam tungsten electrode under 30 cfh of helium, using core wires which fall approximately in the middle of the preferred composition range. Transverse weld properties are shown

Table 8—Composition of All-Weld-Metal Samples Deposited Under Inert Gas

	Ni	*Fe*	*Mn*	*Si*	*Ti*	*Mg*
Wire C:						
Wire	10.53	1.56	0.37	0.35	0.075	0.034
Tungsten arc weld	10.52	1.54	0.33	0.30	0.030	0.020
Consumable electrode weld	10.48	1.47	0.33	0.31	0.054	0.022
Wire D:						
Wire	10.36	1.56	0.36	0.36	0.12	0.037
Tungsten arc weld	10.38	1.60	0.33	0.30	0.04	0.016
Consumable electrode weld	10.31	1.56	0.33	0.34	0.084	0.022

Table 9—Transverse Joint Properties of 90/10 Plate, Inert Gas Welded with 90/10 Filler Wire

	Tungsten arc—argon		*Tungsten arc—helium*		*Consumable electrode—argon*	
	Wire C	*Wire D*	*Wire C*	*Wire D*	*Wire C*	*Wire D*
Yield strength (0.5% ext.), psi	27,600	27,300	24,700	25,900	27,500	27,000
Ultimate strength, psi	45,500	45,700	46,700	45,300	48,900	48,600
Joint efficiency, %	93	93	95	93	100	100
Guided-bend test (face), deg	180, OK	180, OK	180, OK	180, OK	180, OK	180, OK
Free-bend test (face), %	70	72	61	55	40	44
Weld hardness (Rockwell "B")	31–33	37	33–35	33–35	46–56	47–62

in Table 9 and the radiographic soundness indicated in Fig. 5 for 5-in. long vee-grooved butt joints made in the downhand position with these same wires.

INERT-GAS-SHIELDED CONSUMABLE-ELECTRODE PROCESS

Once the filler metal was defined for inert-gas tungsten electrode welding it required only a few tests to confirm the expectation that one filler metal composition could be established for the two inert gas processes. A few preliminary tests were sufficient to show that argon was far preferable to helium and all subsequent test welds were prepared using 50 cfh of argon. With helium, the transfer of metal across the arc was accompanied by explosions and excessive spatter, which practically disappeared using argon. With either gas, welds made with "unalloyed" 90/10 filler wire exhibited some porosity, and the need for a fortified filler wire was again indicated. Porosity was eliminated with as little as about 0.05% of titanium in the wire, and silicon was again effective as a weld strengthener. Fortunately, titanium had no explosive effect on the arc under inert gas, as it did in the case of flux-coated electrodes, and it became possible to use the one silicon-titanium modified composition for both inert-gas-shielded processes.

Insufficient data were acquired to determine whether the better titanium recovery obtained with the consumable electrode process is an inherent characteristic, or is traceable to the greater protection of the larger volume of shielding gas used or to some other variable. Whatever the reason, the consumable electrode process requirements should govern the selection of a filler wire composition completely satisfactory for both processes.

For example, the use of a filler wire containing about 0.20% titanium will result in about 0.15% weld titanium content with the consumable electrode and approximately 0.10% with the tungsten arc process. For conditions of heavy restraint, as in X-welds, such a wire composition would provide a wide margin of safety using the consumable as well as the tungsten electrode methods. With less restraint on the solidifying weld metal or with considerable plate dilution, more titanium can be permitted. For example, a 10-in. long butt joint in $^3/_8$-in. thick plate, involving moderate welding stresses, was uncracked using a 0.31% titanium consumable electrode, which produced cracking in the more heavily stressed X-weld. With still lower stress levels, it follows that the tolerance for titanium will be further increased.

All-weld-metal analyses are included in Table 8 for deposits laid down under 50 cfh of argon, using 0.045-in. diam wire, fed at a rate of approximately 300 ipm. The welding current was 200 amp, reverse polarity. The properties of vee-grooved butt joints prepared under the same welding conditions are included in Table 9 and the level of X-ray soundness obtained is indicated in Fig. 6.

OXY-ACETYLENE WELDING

The response of the 90/10 alloy to oxy-acetylene welding was poorer than its response to any of the other methods studied.

Moderately satisfactory welds were obtained in 0.062-in. sheet but, as the joint thickness was increased to $^1/_4$ and $^3/_8$ in., weld quality became poorer and welds were completed only with considerable difficulty. At least some of the difficulty seemed to be traceable to the comparatively high heat conductivity of the metal, which made it difficult to maintain a molten pool of the proper size without local overheating.

Silicon was effective in reducing weld porosity but the same level of soundness was not attained in gas welding that was reached in coated electrode welding in spite of recoveries which ran as high as 90%. The use of titanium was quickly ruled out because of its tendency to form refractory oxide films on the molten pool.

Of two fluxes evaluated, an all-halide flux provided better protection and better control of the pool than a borax-type flux and, for flame adjustment, a slightly reducing flame was better than either a strongly reducing or an oxidizing flame.

Physical properties are shown in Table 10 for a pair of oxy-acetylene welds made in $^1/_8$-in. 90/10 plate using the all-halide flux (Inco No. 3), a slightly reducing flame and two filler wires, one containing 0.43% silicon and the other silicon-free. Figure 7 shows the X-ray quality of the same two welds. It is apparent from

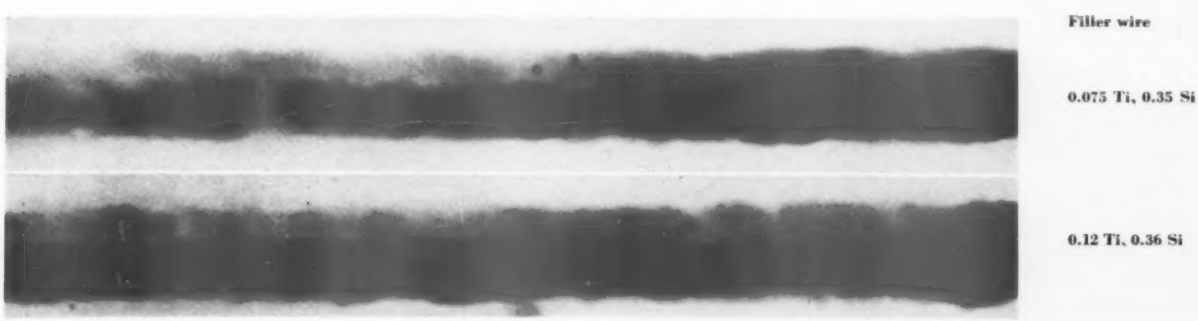


Fig. 6 Radiographic quality of inert-gas metal-arc welds in 90/10 alloy

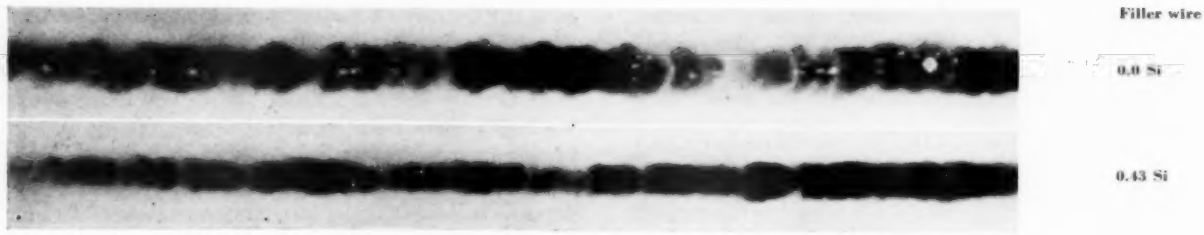


Fig. 7 Effect of silicon on quality of oxy-acetylene welds in 90/10 alloy

Table 10—Transverse Joint Properties of 90/10 Plate, Oxy-Acetylene Welded with 90/10 Filler Wire

	Filler wire	
	0.0 Si	*0.43 Si*
Yield strength (0.5% ext.), psi	17,000	21,400
Ultimate strength, psi	36,100	41,700
Joint efficiency, %	86	100
Guided-bend test (face), deg	180, OK	180, OK
Free-bend test (face), deg	26–44	37–46

Table 11—Transverse Joint Properties of 90/10 Plate Submerged Arc Welded with 90/10 Filler Wire

Yield strength (0.5% ext.), psi	20,200
Ultimate strength, psi	42,100 psi
Guided-bend test (face), deg	180, OK
Free-bend test:	
Face, %	73, no failure
Root, %	54, no failure

an inspection of the data of Table 10 that the heat of welding has had a considerable annealing effect on the base metal and that even with 100% joint efficiency (fracture in the plate), the joint strength is only about 90% of the strength of inert arc or metal arc welds.

SUBMERGED ARC WELDING

The amount of work done on the submerged arc process was rather limited but sufficient to demonstrate that ductile, pore-free welds can be obtained using either the silicon core wire composition of Table 5 or the silicon-titanium inert-gas filler wire defined in Table 7. Welds made with "unalloyed" filler wire were unsound.

Losses of both silicon and titanium to the slag were considerable and, as usual in submerged arc welding, dilution by plate was high, so that little or no benefit was derived, strength-wise, from the presence of either element in the filler wire. For instance, using wire "D" of Table 7 with 0.36% silicon and 0.12% titanium a weld was made in $^3/_8$-in. thick plate, in which the silicon content was reduced to 0.06% and the titanium content to 0.01%. The strength levels were little or no better than those of welds made with "unalloyed" wire. In spite of the high losses, however, the presence of either silicon or titanium, or both, in the core wire is essential to the elimination of porosity. Of three commercial fluxes which were evaluated, only Linde's AB flux had a sufficiently low melting point to produce a satisfactory weld. There may be others, not investigated, which are equally satisfactory but the melting point requirement appears to be such that many or most of the fluxes in current use will be found to have melting points that are too high.

Average transverse properties are shown in Table 11 for three single-pass welds in $^3/_8$-in. thick plate made at 500–550 amp and 32 v d c, with AB flux and $^3/_{16}$-in. filler wire (Wire D, Table 7). The radiographic quality is indicated in Fig. 8.

SILVER BRAZING

In so far as it was possible to determine by laboratory test, the response of iron-bearing 90/10 cupronickel to silver brazing practices was very little, if any, different than that of other binary copper-nickel alloys. Wettability and capillarity were adequate with clearances up to 0.009 in. but best results were obtained when clearances did not exceed 0.005 in. Silver brazing alloy requirements were not critical but, in general, results were poorer using phosphorus-bearing silver brazing alloy than when using the phosphorus-free grades. A conventional, low melting point, fluoride-borate flux provided adequate protection for torch brazing and a dry hydrogen atmosphere was adequate for

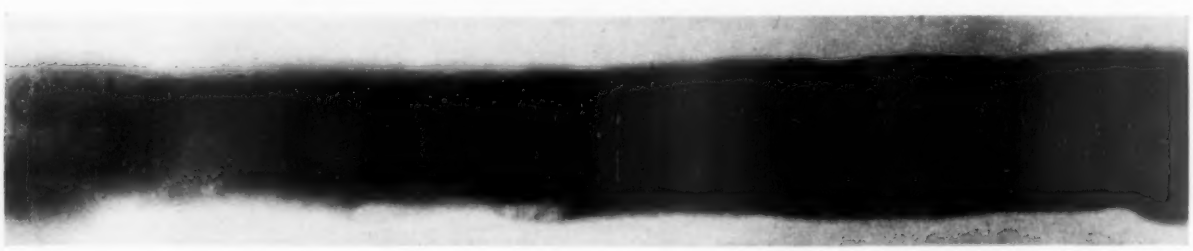
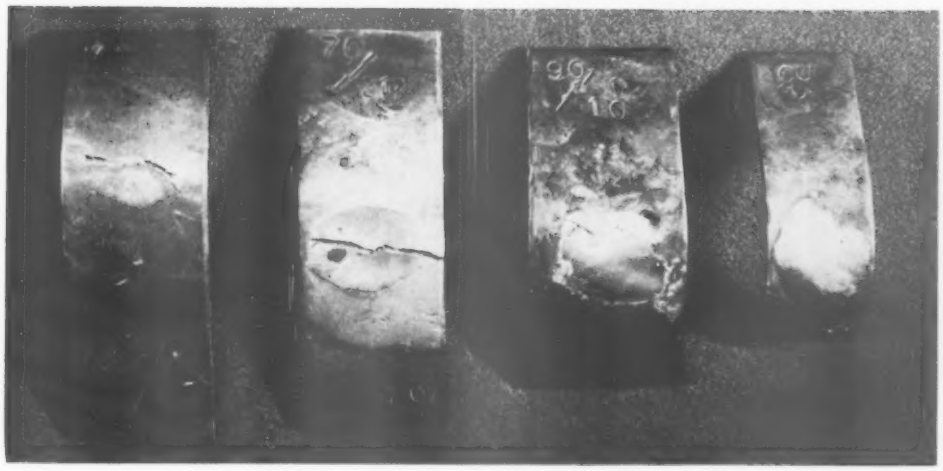


Fig. 8 Radiographic quality of submerged arc welds using 0.12 Ti, 0.36 Si filler wire



Cu, %	30	70	90	100
Ni, %	70	30	10	...

Fig. 9 Embrittlement of binary copper-nickel alloys by silver brazing alloy. Specimens heated to melting point of brazing alloy and bent while still hot

furnace brazing using the phosphorus-free grades of alloy. In torch brazing, the higher temperature required to flow the phosphorus-containing grade accelerated oxide formation which, in turn, tended to overburden the flux. In hydrogen, the phosphorus-containing grade failed to wet out and flow even at temperatures considerably in excess of the alloy's melting point, but supplementary fluxing would undoubtedly help.

Silver Solder Embrittlement

Like other metals in the copper-nickel binary system, the 90/10 alloy was found to be susceptible to intergranular embrittlement if exposed, while stressed, to molten brazing alloy. Figure 9 shows the results of a simple bend test in which this condition was simulated using thin strips of Monel, 70/30 cupro-nickel, 90/10 cupro-nickel and pure copper. All but the specimen of pure copper were severely embrittled. The brazing alloy used in this test contained 50% Ag, 15.5% Cu, 16.5% Zn, 18% Cd and no phosphorus but this behavior is common to most or all of the commonly used silver brazing alloys.

To avoid this difficulty the usual recommendation is to use only material which has been stress relief annealed and, further, to arrange jigging and assembly in such a fashion that any areas in contact with molten solder are free of applied stress. In the case of the 90/10 alloy it is doubtful that it will be necessary to use material in the fully annealed (solution annealed and quenched) condition but, until further experience is obtained, the need for at least a stress relief anneal is indicated, with the further precaution that externally applied stresses should be kept to a minimum.

CORROSION RESISTANCE

An important part of the investigation was the testing of welded joints, prepared by each of the several methods involved, for resistance to corrosion and erosion in sea water. The test was conducted at Harbor Island, N. C., and ran for 60 days from September to November 1952. The test involved spinning a 5-in. diam disk, at 1170 rpm, on the rotating spindle erosion testing apparatus described by Stewart and La Que.[2] Four of the test specimens were exposed as-welded and one was exposed after dressing the weld flush with the plate. From the appearance of the specimens at the end of the test (Fig. 10) it is apparent that the welds themselves, as well as the metal adjacent to the welds, have satisfactorily resisted corrosion and erosion.

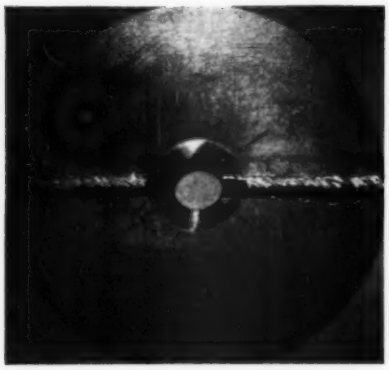
SUMMARY

The welding of iron-bearing 90/10 cupro-nickel, by any one of a number of commonly used methods, appears to offer no unusual problems. Particularly, at no point in the investigation did the potential hazard of embrittlement, due to iron precipitation, become a reality. Corrosion resistance likewise appears to be unimpaired by welding.

The choice of welding method will be governed by the several factors, including cost, availability of equipment and thickness of material involved, which govern the choice in fabricating other readily weldable metals and alloys, rather than by any requirement peculiar to the 90/10 alloy.

ACKNOWLEDGMENTS

This investigation was sponsored by the Department of the Navy, Bureau of Ships. The sponsorship and permission to publish the findings are both gratefully acknowledged. Thanks are also due to N. B. Pilling, Director of the Research Laboratory, and to the management of the International Nickel Co. for making this publication possible.

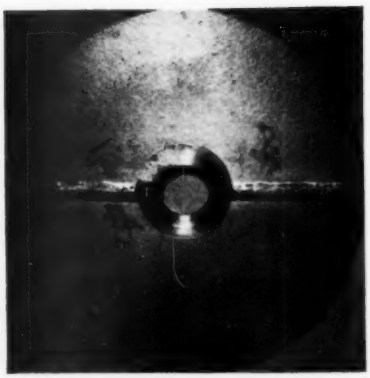


90–10 plate (1.5 Fe)

90–10 weld (1.7 Fe)

70–30 plate (0.5 Fe)

Metal arc

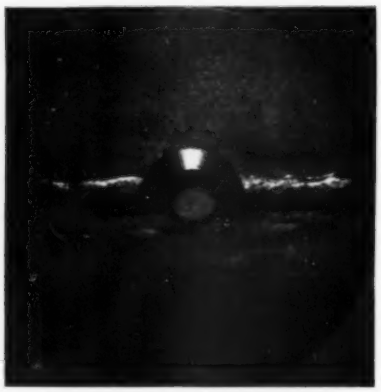


90–10 plate (1.5 Fe)

90–10 weld (1.5 Fe)

90–10 plate (1.5 Fe)

Inert-gas Tungsten-arc



90–10 plate (1.5 Fe)

90–10 weld (1.5 Fe)

90–10 plate (1.5 Fe)

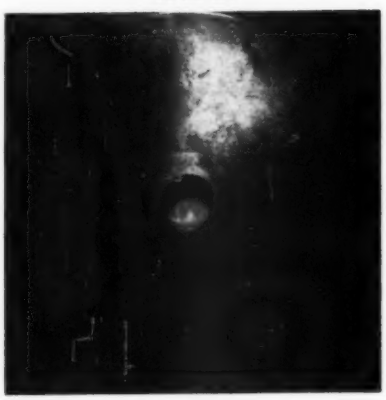
Inert-gas Metal-arc

90–10 plate (1.5 Fe)

90–10 weld (1.5 Fe)

90–10 plate (1.5 Fe)

Oxy-acetylene



90–10 plate (1.5 Fe)

90–10 weld (1.7 Fe)

90–10 plate (1.5 Fe)

Submerged arc

Fig. 10 Appearance of 90/10 Cu-Ni welded corrosion specimens after 60-day rotating spindle test

The authors also wish to express their appreciation to L. C. Minard and C. M. Wessner, welding technicians, for their considerable part in the experimental work required, and to P. E. Le Grand, and A. J. Miller of the laboratory staff for their substantial assistance and advice in certain phases of the program. Corrosion data and photographs were supplied by F. L. La Que of the Corrosion Engineering Section of Inco's Development and Research Division.

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Applications of Alloy High-Strength Steels in Welded Structures

Steel having a minimum yield point of 70,000 psi successfully used in the design and fabrication of the widely different types of equipment found in the ordnance, transportation and mining fields

by Howard L. Miller and Arthur E. Wilkoff

1. DEVELOPMENT OF THE TYPE

THE term "alloy high-strength steel" was selected to apply to steels with higher alloy content and higher physical properties than the group of steels known as the "low-alloy, high-strength steels." This low-alloy group with a minimum 50,000 psi yield point was developed about 1934 to supply a demand for a structural type of steel that could be easily applied, using standard welding procedure, to the construction of railroad cars and units of highway transportation in such cases where reduction of tare weight with allowed increase in pay load would be commercially feasible. Several different combinations in alloying elements are being used to develop this uniform 50,000 psi yield point in rolled shapes and plates and sheets that can be cold formed to a fair extent and welded at normal shop temperatures and placed in service without requiring a stress-relieving treatment, especially in such large structures as railroad freight cars or large truck trailer bodies.

To a more limited extent, a field for application of still higher strength materials began to develop during World War II and the U. S. Ordnance Department was instrumental in developing a demand for a material to meet requirements of 70,000 psi yield point after welding and stress relieving at around 1100° F. The stress-relieving operation is a prime requisite, for two reasons. The first reason is the necessity of preventing warpage or movement of the structure during machining, subsequent to welding; the second reason for stress relieving is a desire to improve strength and shock resistance in the structure as a whole, the heating and slow cooling operations neutralize the locked-in stresses due to thermal expansion and contraction in the welding zone in fabrication.

Howard L. Miller is with the Republic Steel Corp., Cleveland, Ohio, and **Arthur E. Wilkoff** is President of the Youngstown Steel Car Co., Niles, Ohio.

Presented at the AWS National Spring Meeting held in Houston, Tex., June 17, 1953.

Fig. 1 This is the 155 MM gun known as the "Long Tom." The mount, made of welded alloy steel, is approximately 3 tons lighter than the previous design

2. WARTIME APPLICATIONS

Long Tom

One of the first applications of this type of steel was in the construction of the MI gun carriage for the 155-MM 50-caliber cannon, known to the Army as the "Long Tom" (Fig. 1). The tare weight of this gun carriage was reduced from 10 tons to 7 tons when redesigned on the 70,000 yield point basis and much better mobility for the gun was obtained.

Experimental drop cans made from this steel in 28-gage sheets cold rolled to 125,000 yield point were made up for tests by the Air Force for parachute dropping the disassembled 75 MM Mountain Type Howitzer. The end of the war intervened before this work was finished. Some new research along this line has been considered recently.

British "Valentine" Tanks

During the last war a large number of tank suspension units (running gears) were produced in this country and Canada for application to the British 18-ton infantry tank, known as the "Valentine" tank (Figs. 2–4). Steel of 70,000 psi yield point was used in all the parts in this assembly that were made from plates. Other parts welded into the assembly were alloy steel castings and forgings of similar specified physical properties. The unit was a complicated assembly to distribute the weight of the tank on two small and one large wheel in

each of the four units so that the load on all wheels was equal. The two small wheels acted as a unit and through lever arrangements took up two-thirds of the load and the large wheel one-third, using the same equalizer system long used by farmers in a "three-horse hitch" for pulling farm machinery.

The plate parts were hot or cold formed to shape as the requirements to be met ruled and, after all welding in of plates, castings and forgings was completed, the parts were stress relieved before machining.

All welds were hand welds and mineral coated rods were used in both fillet and butt welds. These units performed very satisfactorily even under such drastic field tests as running a tank at full speed up an inclined ramp with a 3-ft drop at the end of the ramp.

Without the high strength type of steel and the welding art, it would have been almost impossible to engineer this type of unit. All manual welding was done with AWS Grade E7010 and Shield Arc 85.

Fig. 2 Stub axle for the large wheel of the British "Valentine" tank. Cone is 1/4-in. plate

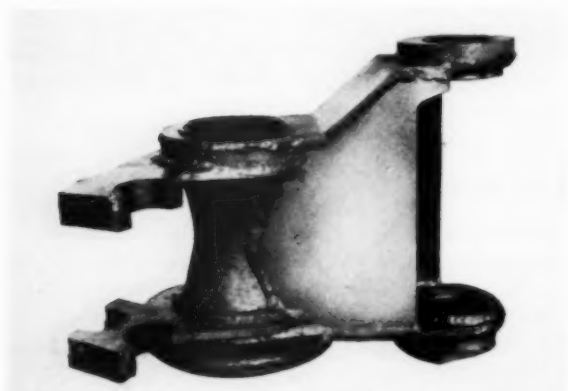

Fig. 3 British "Valentine" tank assembly of supporting frame for small wheel rocker arms. The two welded plate lugs at left engage with a pin to hold one end of shock absorber

Fig. 4 Assembly showing main frame member (which was bolted to side of tank) and the three axles for the bogie wheels

Electrode diam, in.	*Amp*	*Arc voltage*
3/16	150–220	24–28
1/4	200–300	28–32

3. POSTWAR APPLICATIONS

After the close of the war several new applications for this type of steel were developed. While the total tonnage of steel involved is rather small, the applications themselves are quite important in considering the results obtained either in the over-all engineering design or in the longer life obtained in service due to high strength and in some cases a higher resistance to corrosion or abrasion.

Fig. 5 Welded underframe assembly used in all Budd Co. standard stainless steel railway cars

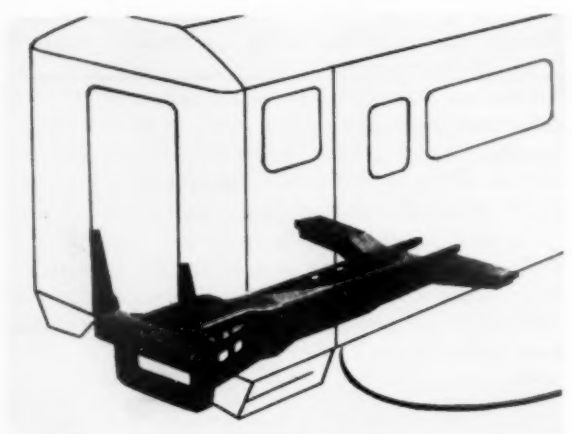

Fig. 6 Location of welded underframe assembly

Railway Passenger Cars

One of the principal applications in point of amount of steel required as well as its importance in the structural design effect is the production of end underframes for all of the Budd Co.'s stainless steel railway passenger cars (Figs. 5 and 6). Cold- and hot-formed plates of 65,000 psi yield point are welded in subassemblies and then into the final assembly and then stress relieved and checked on a plane table for possible distortion before shipment. The dimensional tolerances on this large welded assembly are much closer than in general practice as the assembly has to fit accurately at many points into the stainless steel body that is engineered to very close dimensional tolerances. It must support all the end-to-end shocks in starting and stopping long trains as well as the up and down loading under high-speed operations. There have been over 1100 of these units completed and placed in operation since 1946 and there has not been a single failure of these units under normal operating conditions.

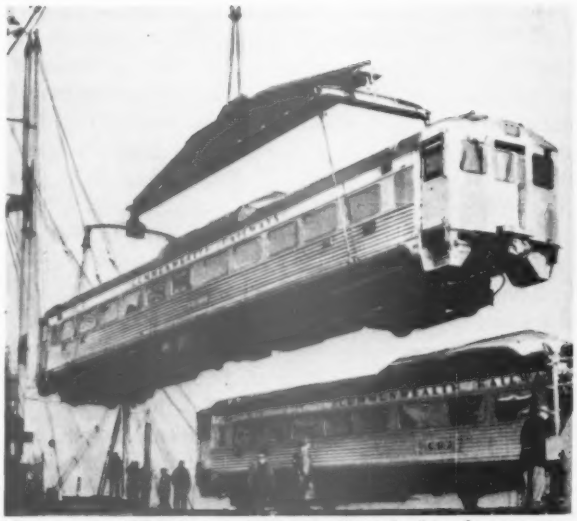

Fig. 8 An RDC being hoisted aboard ship for export. Note under-car equipment held in place by welded steel brackets

Rail Diesel Cars

THE new Budd Co. RDC (Rail Diesel Car) has become a very important figure in the passenger equipment field within the last two years (Fig. 7). Powered by two 275-hp Diesel engines, direct coupled to Allison torque converters on the driving axles, this stainless steel bodied, lightweight passenger car is being put into service in increasing numbers by the railroads, particularly on short run suburban traffic, but also is replacing heavier equipment on longer runs where traffic is light and full crew trains with engines are unprofitable operations. The end underframe and complete truck frame, bolster and spring plank are all made of welded alloy steel, formed, welded and stress relieved to a minimum 65,000 psi yield point. The estimated saving in weight of these weldments in use instead of cast steel parts is between 4000 and 5000 lb per car.

All of the brackets and framing for supporting under car equipment of the RDC are made up of weldments of high-tensile steel. This equipment includes the two Diesel motors, electric generators for powering the air conditioning, lighting and air brake compressors. The motors are removable as complete units for changing or overhauling. The end underframes of this car are similar but lighter than the standard car.

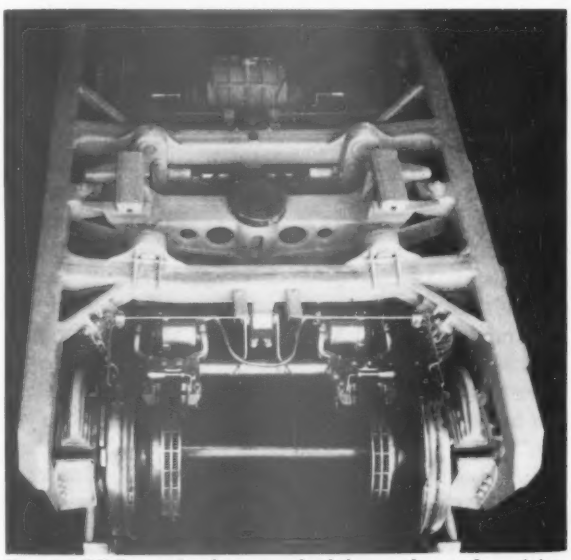

Fig. 9 RDC truck photographed from elevated position showing outer end of truck

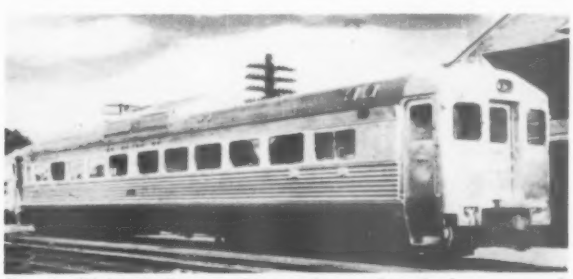

Fig. 7 Welded alloy steel is used in end underframe, truck frame, Bolster and spring plank of this Rail Diesel Car

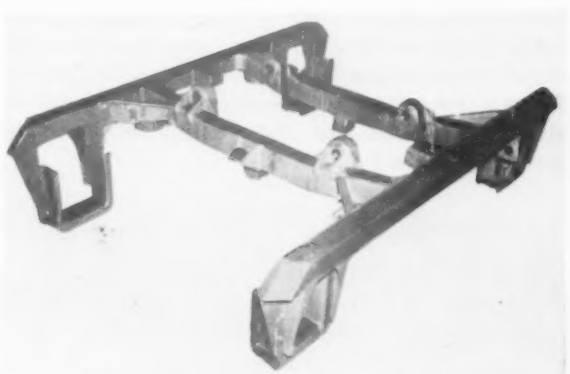

Fig. 10 RDC truck—main frame weldment

The truck of the RDC shown in Fig. 9 has, at the extreme top center, a Spicer Drive to which a drive shaft from the Diesel motor is connected with a universal joint. The longitudinal and cross-frame members are made up for formed channel sections welded together to form rectangular box sections with high section modulus for the weight involved. The center plate and side bearings carry the full weight of the car body. The Bolster is a box section of formed plates welded together. The Bolster rests on two large size coil Spring assemblies which in turn rest in pockets on a spring plank of formed and welded plates. The spring plank rests on two cross members which connect at the ends with the four swing hangers which are hung on pins through the cast-steel parts welded to the cross members. The load is then transmitted through the frame members to the four coil springs which rest on the equalizer bars, which in turn rest on top of the axle journal housings. This rather complicated suspension system is required to give smooth riding properties to the car in traveling over the rails and around curves at speeds up to 80 mph.

The side rails of the RDC truck frame (Fig. 10) are made up of two cold-formed channels with flanges butt welded together. The two cross members are made in the same way. The bearing boxes on the ends are also formed and welded to the main frames. The pedestal binders are the three-sided closure sections that are bolted to the flanges of the box frames. Originally they were made from a long formed channel in one piece with inserts at the flange corners. The later design made of three short sections welded together gives additional strength and resistance to distortion due to the web of the bottom section continuing out to the full width of the side flanges.

In production the pedestal binders are made up and tack welded in position to the frames for stress relieving. After this operation the assemblies are set up for drilling bolt holes through the flanges and the side frames before cutting the pedestals loose from the frames. This operation assures perfect alignment of bolt holes for later assembly after the axles and bearing housings are in place. The pedestal binder's function is to support the jaws of the axle housing and to prevent wheels from coming loose from the trucks although allowing up and down movement of the frame upon the axle housings.

The center plate and side bearing supports of the Bolster (Fig. 11) are made up from hot-formed plates welded and stress relieved. The center plate is a forging of alloy steel and is welded integral in the Bolster. The end projections have holes for connecting the shock absorbers which stabilize the forward and backward movement of the Bolster.

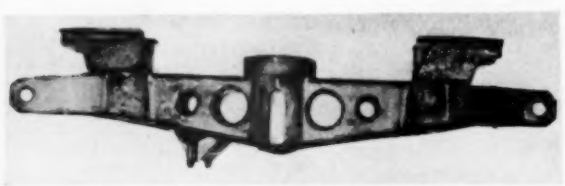

Fig. 11 RDC truck—side view of Bolster

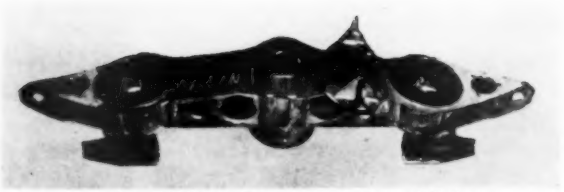

Fig. 12 RDC truck—bottom view of Bolster

On the underside of the Bolster are pockets for the large-diameter coil springs on which it rides, as seen in Fig. 12. A part not shown is the spring plank. This is a welded plate structure that has connections for the swing links which connect it to the frame and pockets for the large springs which support the Bolster. This welded truck assembly of 65,000 yield point steel enables the designer to save about 1100 lb on each of the two trucks per car.

All plates used are medium-alloy high-strength steel welded and stress relieved to minimum 65,000 psi yield point. The combination of this type of steel and weldind design has been very successful in operation and is one of the important factors in enabling the engineers to produce a modern high-speed car with a high-strength weight factor in this very important part.

AWS Grade E7011 electrodes were used on all underpass welding on the Budd underframes, trucks, Bolsters and springplanks. Size of electrodes, amperage and arc voltage used were as follows:

Electrode diam, in.	*Amp*	*Arc voltage*
5/16	150–200	24–28
1/4	250–300	28–32

AWS Grade E7020 electrodes were used on all finish pass welding. They measured 1/4 in. in diam and were deposited with a setting of 300–340 amp and 30–32 v.

Coal and Ore Mines

Mining of coal and iron ore are part of the operations of the principal steel companies and, of course, they are

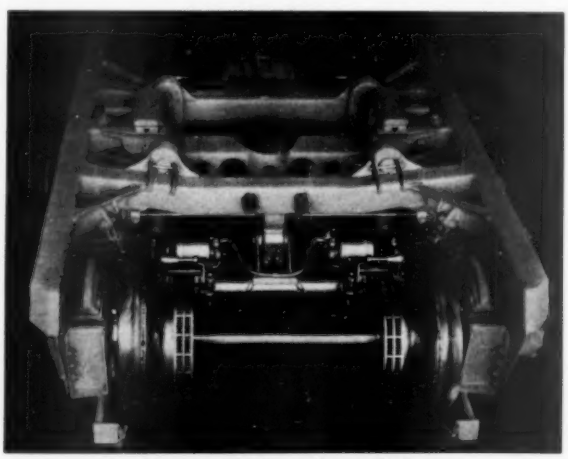

Fig. 13 RDC truck—end view

interested in the maximum performance of their equipment, particularly in the cost per ton of product handled as represented by initial cost and maintenance over the life period of the various units. It has been found out that in certain mines or conditions, the higher initial cost of the alloy parts is more than justified by the longer life or higher efficiency in terms of pay load increase when lighter tare weight is a factor. Thus mine cars operating on fairly level trackage give better over-all life cost when normal thickness of plates is used, and the longer life in service in the payoff, whereas in a hoisting skip with a load limit on the cables, the lighter designed skip will pay off on the increased pay load resulting from the higher-strength, thinner material in its design.

In the case of coal washers, abrasion and corrosion combine to force frequent expensive shutdowns for replacement of failed chute plates and guides. Hence, an initially expensive type of stainless steel often proves to be the lower final cost material. There are many other conditions however, where alloy and low-alloy materials are satisfactory and show lower long-run costs.

In coal and ore mines applications have been made of the alloy plates and sheets in mine cars, skip cars, transfer car bodies, bottom plates on loaders, cutter chain beam sections on coal-cutting equipment, hoist skips, loading chute plates and various plates in coal-washing equipment.

Corrosion from damp coal in some of our mines is such that common steel plates, used in coal loaders (Figs. 14 and 15), seldom last one year. A replace installation of alloy high-strength plates in 1949 is now being renewed after four years in service. The plates are welded to a supporting frame from the underside and all joints between plates are butt welded. Low-hydrogen coated rods of 0.15 C grade steel are used and

Fig. 14 General view of a coal loader. NES 70 plates are used on the apron and on the bottom and sides of chutes

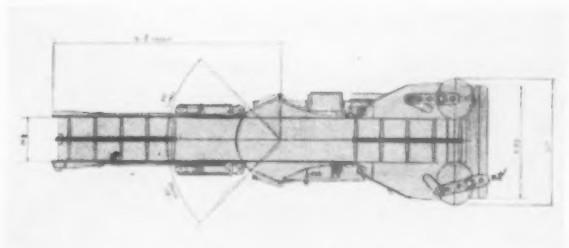

Fig. 15 Diagram showing where plates of NES 70 were used to gain longer service at lower net cost in coal loader

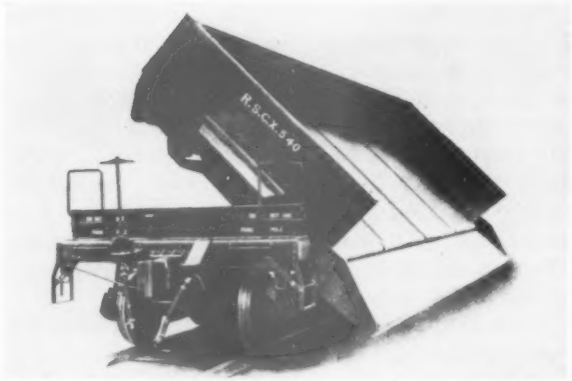

Fig. 16 Two hundred of these alloy steel cars for handling copper ore and waste rock are now in service. Some are more than six years old

no stress relieving is required. The plates were applied in the as-rolled condition. On some other jobs where heavy, hard materials are handled a high hardness, heat-treated alloy steel plate may be found less expensive even though stainless steel armor-type rod may be required.

Alloy steel plates have shown exceptional durability in a car for handling copper ore and waste rock in the Bingman Canyon Mine in Utah (Fig. 16). Bottom body plates are $^{3}/_{4}$-in. thick and door plates $^{1}/_{2}$-in. thick. In one case the fabricator ordered the floor plates cut to length equal to the width of the floor and cross welds were made over the top surface of the 8-in. I-beams which run crossways of the car and support the floor on about 18-in. centers. The present fabricator is using long plates cut to two pieces per car length and one-half the car wide. The end butt welds in the center occur over adjacent cross members. A backing strip of 2- x $^{1}/_{4}$-in. common steel is placed between cross members on the longitudinal weld down the center. On the side edges, the $^{3}/_{4}$-in. plate is welded to the top flange at the side sill channel and a $^{1}/_{2}$-in. curved apron section is butt welded into the floor plate and the channel. The floor and apron plates are tack welded to the channel with a $^{5}/_{16}$-in. gap and using $^{3}/_{16}$-in. manganese moly rod and submerged arc type 80 flux. The weld is made in two passes at about 10 ipm each pass. This operation joins all three elements in a good structurally sound assembly that has stood up well under very severe impact loading and dumping conditions in this mining operation. The end plates are fillet welded to the floor plates with three passes on the inside of the joint and skip welding on the backside.

Fig. 17 Section through a $^{3}/_{4}$-in. floor plate butt weld with backing strip (Rockwell B hardness, as-welded)

The floor plate butt weld, in the as-welded condition has a Rockwell hardness range of 83/94 B in first pass and 94/95 B in second pass (Fig. 17). Hardness of parent metal is 100 RB and range in heat-affected zone from 97 to 99 RB. This weld was made with a $^3/_8$-in. gap on straight-cut edges, no angle scarfing. Automatic submerged-arc machine with (manganese moly) $^5/_{16}$-in. rod and Unionmelt type 80 flux. Two passes each at 8 ipm travel with 700-amp setting. The side sill, bottom and apron plate weld is very similar to this section.

Physical tests on sections across the weld zone of this welded sample showed the following properties:

Condition	*Yield point, psi*	*Tensile strength, psi*	*—Elongation—* *2 in.*	*4 in.*	*Brinell hardness no. plate*	*Fracture*
As-welded	83,200	98,600	17.5	9.5	228	Weld. fusion line between 1st and 2nd passes
SR-1050	74,000	96,900	23.5	14.0	217	
SR-1100	72,300	94,100	26.0	16.0	207	

None of the over 200 cars in service has developed any breaks in the welded zones, although stress relieving of these large welded bodies is not possible.

The end plate is welded to the bottom plate as follows: The end plate is inclined at a slight angle to the floor plate and toward the end of the car (Fig. 18). After tacking in place the first pass was made on the inside face of the joint. The first pass was made $^3/_{16}$-in. A. O. Smith No. 65 rod and 165 amp. The aim was to get deepest penetration into the joint. The second pass inclined more to widen the base of the fillet on the floor plate. The same rod and setting were used. The third pass was made with $^1/_4$-in. hot-rod fillet-type rod and the object was built up to the end plate but to avoid fusing the weld line between the second pass and the floor plate. This object was to normalize the fusion zone of the second weld and at the same time build up the fillet on the end plate and obtain a smooth, slightly concave fillet. The skip weld on the back side was put in with one-pass hot rod about 4-in. weld and skip. Rockwell hardness in this zone is as follows:

96 RB	Parent metal $^1/_2$-in. plate
99 RB	Parent metal $^3/_4$-in. plate
90 RB	1st pass 92 fusion zone $^1/_2$ in.
83/89 RB	2nd pass 93 fusion zone $^3/_4$ in.
86/87 RB	3rd pass
92 RB	Skip weld 96 fusion zone

The underframe channels and I-beams in these applications have been of 50,000 yield point alloy steel, either Inland Hy-Steel or Bethlehem Mayari R.

The object of these installations was to obtain a unit that would stand up to rugged loading conditions, using power shovels to handle large chunks of heavy rock and to keep the cars out of the repair shop. Reorders over a period of over six years seem to indicate that welded construction alloy, high-strength steel has filled the bill.

All of these cars have gone into service in the as-welded condition. All steel furnished has met minimum 70,000 psi yield point in the as-rolled condition. Sample heat analysis is as follows:

C	0.18
Mn	0.75
P	0.015
S	0.025
Ni	1.75
Cu	1.20
Mo	0.25
Average yield point, $^3/_4$-in. plate, as-rolled, psi	73,000
Average tensile point, $^3/_4$-in. plate, as-rolled, psi	98,000
Elongation, 2 in., %	17

Scrapers, used to gather iron ore after shooting it down from the face and dragging it to the chutes leading to loading bins or skips (Figs. 19 and 20), encounter a serious problem in breakage in the side arms when made of ordinary structural bars. This problem was met by the use of alloy, welded steel.

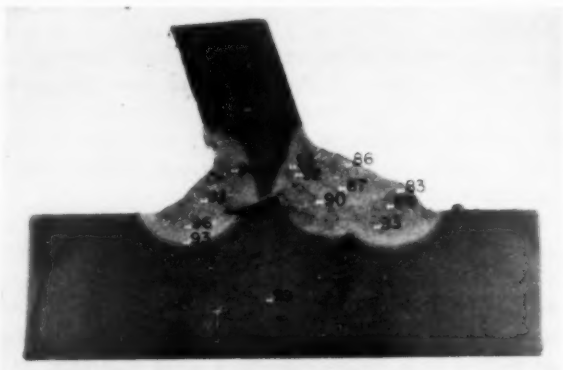

Fig. 18 End plate to bottom plate weld (Rockwell B hardness, as-welded)

The side bars are $2^1/_2$ x 6 in. in cross section. In use the cable hitch lifts the scraper from the rock floor and

Fig. 19 Ore mine scraper for gathering iron ore on mine floor

Fig. 20 Back side view of scraper. Making the entire assembly, with the exception of the blade, edge out of alloy steel, stress relieved has eliminated breakage

moves it overhead to the loose ore. There it is dropped on the floor behind the loose ore, and then it is pulled forward by cables, scraping or bulldozing the ore chunks along the floor to the hole-in-the-floor chutes. This method has to be used in mines where the ore vein is on too great a slope to permit operating mine cars on a track or self-propelled, rubber-tired loaders. Dropping the scraper on the piles of hard ore or the rock floors causes considerable replacement of side-bar assemblies, the fractures occurring at the place where the triangular 1-in. side plate is welded to the side bar.

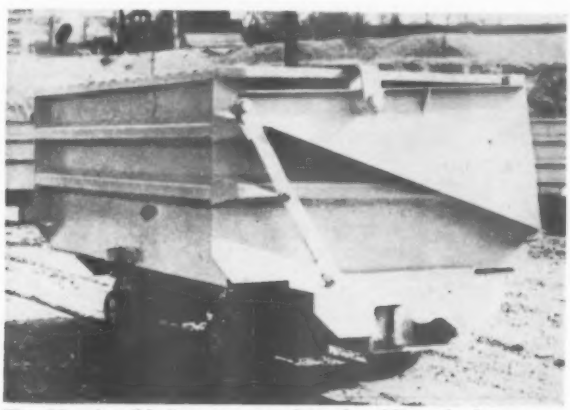

Fig. 21 A welded ore car used in the Adirondack iron ore mines of Republic Steel Corp.

Ore gathered by scrapers, runs down chutes into Granby-type ore cars (Fig. 21). There are over 100 of these cars in operation. The first 25 cars were all welded together by the maintenance welders at our Port Henry Mine using AWS E6010 for fillet welds and AWS E7010 for butt welds. No stress relieving was used and all cars have stood up well under rugged service conditions. Subsequent orders of these cars were made by regular car builders. All plates were made from the high side chemistry and all forming was done cold in hydraulic presses. One-half inch plates were used on bottoms and $^3/_8$-in. plates were used for sides and doors. Box section stiffeners were cold formed and welded to body plates with AWS E6010 electrodes.

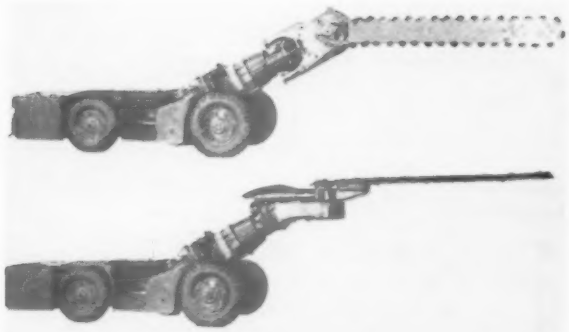

Fig. 22 Two views of a coal cutter with cutting blade at different angles

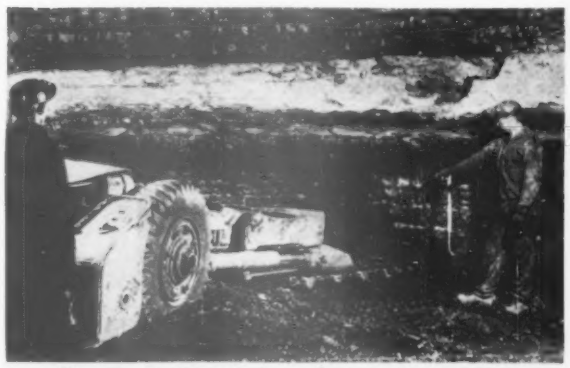

Fig. 23 Coal cutter in under-cutting position

One of the most efficient mining machines on coal veins is the coal cutter (Figs. 22 and 23). This machine is almost the same in principle and operation as the power-driven chain saws which have taken over from the "axe and saw men" in our timber forests. The coal cutter is really an endless chain belt running on a frame with a driver and idler wheel at opposite ends of a frame called the cutter bar.

Various machines are designed to hold the cutter bar in a vertical cutting position but the undercutting position (Fig. 23) is the operating condition with which we are most concerned. In this operation the cutter bar is placed in a horizontal position just barely clearing the floor and as the teeth chew out the coal the machine moves forward toward the face of the vein and cuts a slice of coal about 18 in. wide, running back under the vein to the limit of the cutter bar 10 or 15 ft. When a few side-by-side cuts have been made, the cutter is withdrawn and holes are drilled in the top of the vein under roof slate, and light explosive charges or carbon dioxide expansion tubes break the coal down from the roof for removal by the loading machines. However, sometimes the coal will come down of its own unsupported weight and thus pin the cutter bar under a considerable pressure of coal, imposing a problem for removal of the cutter. Working the manipulator arm up and down with a pumping motion while pulling backward is the general method of extracting a pinned-down cutter. This sets up bending strains in the cutter bar.

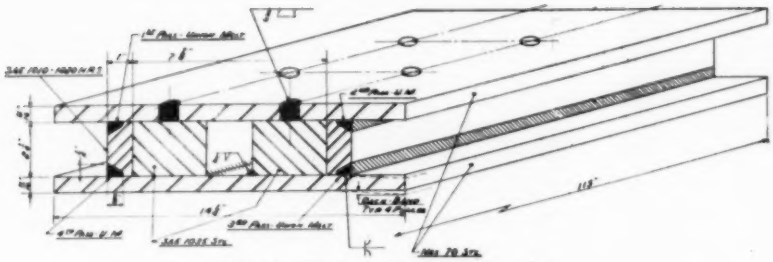

Fig. 24 Design of coal-cutting bar

The coal-cutting bars under discussion were made for the Joy Manufacturing Co. by the Lewis Welding and Engineering Corp. The top and bottom plates (Fig. 24) are $^{11}/_{16}$-in. x 14-in. NES 70 plates. The heavy inside bars are SAE 1035 and the smaller bars SAE 1015.

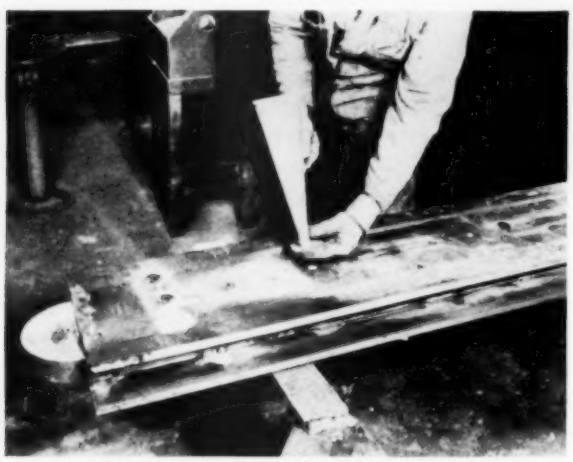

Fig. 25 Making plug welds with squirt welder

A squirt welder was used in making the plug welds (Fig. 25). Holes, $^{3}/_{4}$ in., are drilled in the plate. The data on this operation is that Lincoln squirt welder is used with a setting of 450 amp, 6 v, $^{5}/_{64}$-in. m.s. wire and Linde 20 D white flux are used. A hand bead is first applied around the inside circumference to build up a fillet around the bottom of the hole and then the entire hole is welded full in one setting, the experience of the operator determining when to cut off current. A rotary motion is used to insure full fusion in the plug (Fig. 26).

Stress relieving increases the hardness in the parent metal and heat-affected zone about eight points Rockwell average but reduces the weld plug hardness about four points average (Figs. 27 and 28).

Four grooved fillet welds run the length of the bar (Fig. 29). All welds made in two passes and all welds run in the same direction. The machine setting is 1100 amp, 32 v, $^{1}/_{4}$-in. weld steel wire, travel $8^{1}/_{2}$ to 9 ipm, 20 D white flux used and all passes in the same direction. A small amount of straightening is required which is done under a press after stress relieving at 1100° F. The minimum yield point of the NES 70 steel plates is 75,000 psi after stress relieving. Values as high as 80,000 psi are often obtained. The high yield point of the steel plates used enables the operator of the machine to remove the bar from under the coal after a fall under conditions in which a lower strength steel would be bent out of line so far that the cutter chain would not run freely.

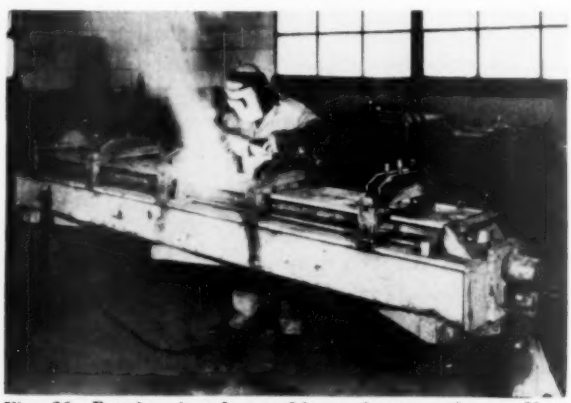

Fig. 26 Putting in plug welds on bottom sheet. Note rotating fixture jig

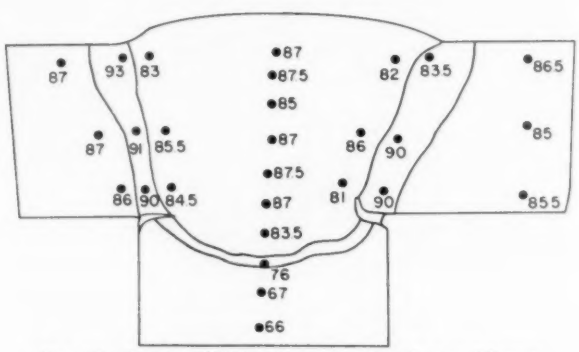

Fig. 27 Rockwell B hardness in the plug weld zone as-welded

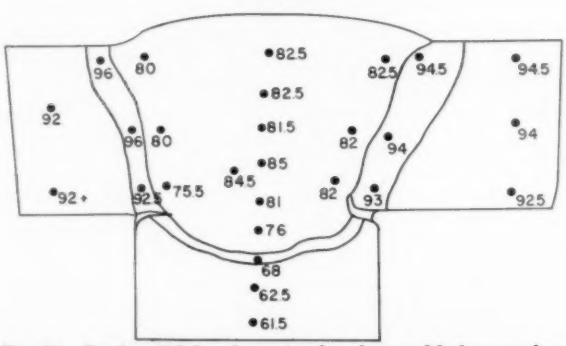

Fig. 28 Rockwell B hardness in the plug-welded zone after stress relieving at 1075° F

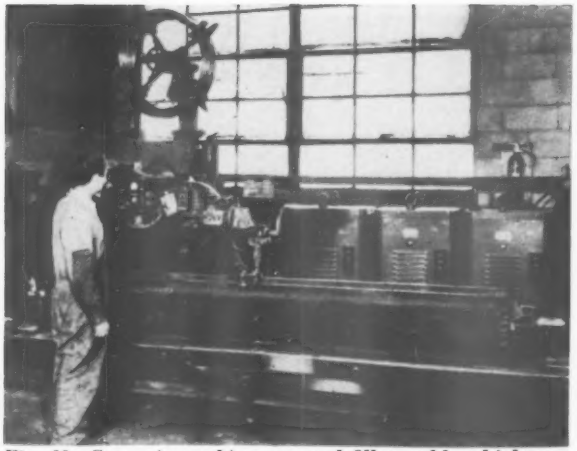

Fig. 29 Setup in making grooved fillet welds which run the length of the cutting bar

The cutter chain with removable teeth in the links runs forward on the back side of the cutter, around the end plate and then back toward the sprocket drive wheel, carrying the coal cutting along with it to clear out the cut. This cutter bar has been a recurring order for alloy plates for several years and has performed very satisfactorily in our own Republic Steel coal mines, as well as in mines of many other customers of the Joy Manufacturing Co. (Fig. 30).

Fig. 30 Welding the round end for the chain return

Another application in the iron mines that is of interest is the application of multiple plate laminations used to replace the solid bar forged bails for skip hoists (Fig. 31). Some failures of the single-piece bar type of skip bail have occurred due to sudden impact with "crystalline type" fractured surfaces. This difficulty has been entirely eliminated by making up these bails of laminated $^1/_4$-in. plates, plug welded together.

The five thicknesses of $^1/_4$-in. plate have staggered holes so that only one thickness of plate is welded at every plug and no two plug welds occur at exactly opposite sides of the same plate. A wrap around flat bar is groove welded to the outer plates all around the

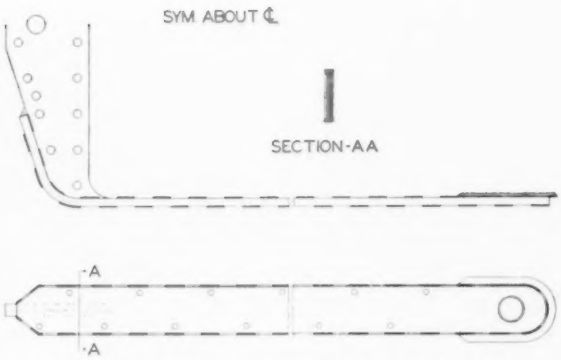

Fig. 31 Laminated-type bail for iron mine skip

edges of the bail and thus the edges of the plate laminations are protected from any wedging action that might tend to separate them if struck on the edge of the assembly. All welds in this case were made with low-hydrogen rod. All fabricating and stress relieving on these jobs has been done by the Jennings Manufacturing Co.

Ladle Hooks

One of the most important and critical pieces of equipment in a steel melt shop is the large ladle hooks, a pair of which are used to lift the large ladles of molten steel (up to 300 tons at a heat) and carry them across the open-hearth floor to the ingot teeming platform. Failure of ladle hook, dumping its load of molten steel at around 3000° F can cause terrific damage by resulting explosions and loss of life.

The single-section forging has long been eliminated in this part and a laminated structural steel plate hook, riveted together, generally has been used on all the large open-hearth ladles.

Republic Steel recently enlarged a group of furnaces in one of their steel plants increasing the melt from 200 up to 220 ton capacity.

New and stronger ladle hooks were required but the piers on which the ladle rests when tapping the heat, and the side of the ladle were so spaced that the thickness of 7 in. of the ladle hooks could not be increased. With only a 7 in. wide trunion bearing the fiber stress at the loading point would be beyond a safe loading for ordinary structural steel.

It was decided to use the 70,000 yield point alloy steel for this job. Also the practice of drilling holes through the stack of plates and riveting them together, admittedly sets up stress areas around the holes which reduces the effective strength of the cross-sectional area by about 20%.

It was decided to plug weld assemble these hooks and gain the extra strength of material (Fig. 32). The design was worked out using $^5/_{16}$-in. plate for all but the two outside plates which were to be $^1/_2$ in. thick. Staggered pattern holes were drilled and assembly began.

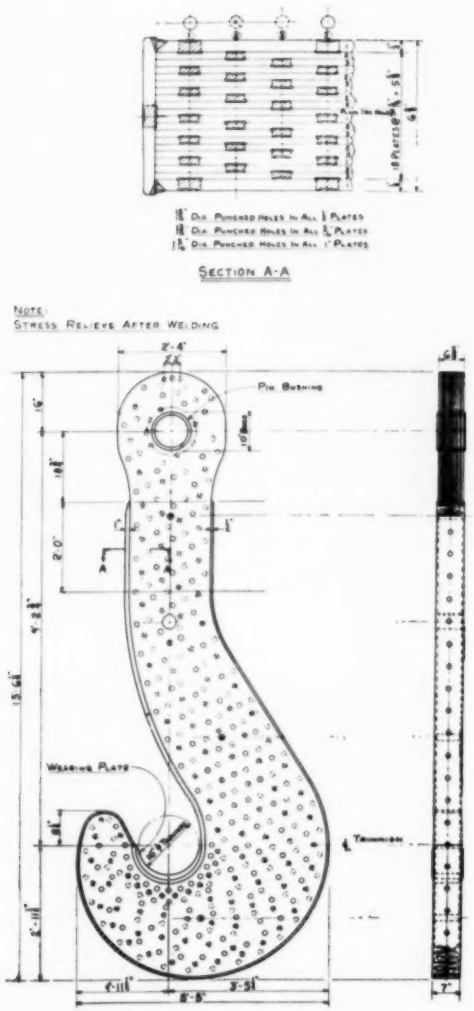

Fig. 32 Detail design of welded alloy steel ladle hooks

Fig. 33 Alloy high-strength steel ladle hooks in service

The middle plate was laid flat and another plate indexed on top of it and plug welded to the middle plate and all over-fills ground flat. The assembly was then turned over and another plate plug welded to the middle plate. By alternating the welding of the plates in this manner the entire assembly was finished and laid flat without bending or distortion when cool.

A $^{3}/_{4}$- x 7-in. flat was bent around the outer edges across the open edges of the laminations and welded to the outer plates in groove welds.

Bushings for the main pins were groove welded to the outer plates being press fit into machined holes through the thickness of the plates.

The entire hook was then stress relieved and a graphitic iron liner placed in the trunnion bearing, this latter part being renewable. Ten of these large hooks were completed with practically no difficulty and all have been proof tested in accordance with the standard American Iron and Steel engineer's formulas and have been in service for about one year.

All plug welding on the ladle hooks was done with AWS Grade E7020 electrodes

Electrode diam, in.	*Amp*	*Arc voltage*
$^{5}/_{16}$	200–250	28–30
$^{1}/_{4}$	300–350	30–32

Buses

The Mack Manufacturing Co. Engineering Division in connection with investigation of materials and methods of reducing weight of bus vehicles, developed an alloy-welded construction rear axle housing which was tested out and adopted as standard on their C-50 model, 50-passenger bus. Adoption of this design with steel yield at 60,000 psi minimum, enabled the manufacturers to reduce the weight of the axle housing and increase the over-all strength.

This axle housing was developed as a part of cold-formed channel sections, forming a banjo-type unit (Fig. 34). The two sections were bent around in the middle to form two halves of a circle and the flanges then butt welded together with small gusset plates welded into the curved sections of the flanges to form complete circular openings in the center.

The hot-rolled plate material was sheared into blank size and pressed cold in one operation. The next operation was stress relieving at 1050–1100° F. The parts were withdrawn at stress-relieving temperature and restruck for sizing, and water-cooled dies were used.

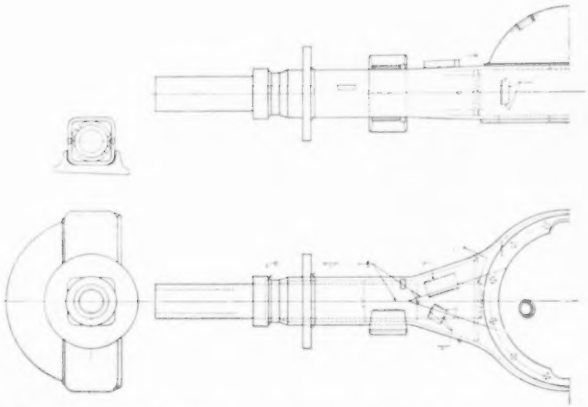

Fig. 34 Detail design of bus axle housing for 50-passenger bus

After edge trimming for fit-up, the end fittings and stub axle tubing was welded in place in one section then the other half tacked into position and the flanges and gussets were welded in with shielded-arc automatic welders using mild steel rod with low-hydrogen flux.

Due to the fact that the stub axle was a heat-treated section that could not be reheated to stress-relieving temperature, it was not possible to stress relieve the finished weldment.

However, the chemistry of the steel used is of sufficiently low hardenability in the welded zone in the as-welded condition, and it is possible to produce this axle housing in the manner shown, maintaining a yield point of 65,000 psi and without stress relieving the welded assembly; no trouble has been encountered in the many thousands of miles that the units have been in service.

Ordnance

In the field of Ordnance the gun carriage intended for airborne service must be extremely light and strong. In such designs we find yield points running up to 120,000 yield point obtained by heat treatment.

"Muzzle Brakes"—or as sometimes called "blast deflectors"—require yield points around 100,000 psi with high impact values at low temperatures. Welded alloy steel plates which are hot pressed to shape, welded

Fig. 35 Position of the welded high-strength alloy-steel housing of the 50-passenger Mack bus

and then quenched and drawn have completely replaced the cast-steel brakes used in World War II due to the higher blast pressures on the newer tank and antitank guns.

CONCLUSIONS

Now as to the particular characteristics of the type of steel we are most interested in for this paper: This particular grade was developed to meet the U. S. Army Spec. No. 57-114-1A, Class C which calls for a minimum 70,000 psi yield point after stress relieving not less than 4 hr at 1100° F. It must also show not more than 300 Vickers Brinell in the welded zone as: welded condition in the particular weld test as specified and must show a tough gray fracture in the stress-relieved condition on a notched break test when broken in a vise with a hammer. Later specification for higher than 70,000 yield point material in the heat-treated condition calls for fairly high impact strength in proportion to yield strength.

The steel used in the welded applications which we have discussed is made by using nickel, copper and molybdenum as alloys. This combination of alloying elements will dissolve almost entirely in the ferrite and produce a regularly tough material in proportion to its strength. The stress-relieving temperature of 1100° F generally will develop an increase in the yield point and notch toughness above the as-rolled condition. The transition temperatures are generally quite a bit lower in the as-rolled or stress-relieved condition than other analyses of corresponding strength, and in the quenched

Table 1—NES 70—$^5/_8$-In. Steel Plates, Butt Welded

One pass hand weld on butted edges of plate. Opposite side machine grooved to full bottom in hand bead. Two passes submerged arc using NES 70 rod and low-hydrogen flux. Heat treat and condition as shown:

				—Elongation—			
Test no.	*Condition*	*Yield point, psi*	*Tensile strength, psi*	2%	4%	*Break*	*Plate Brinell*
1	As-welded	92,200	108,600	15.5	10.2	Weld	201
2	S.R. 1075° F	94,100	107,400	25.5	16.0	Plate	197
3	Quench 1650, D. 1000	135,600	145,900	12.0	7.0	Weld	269
4	Quench 1650, D. 1125	107,800	121,100	27.0	17.0	Plate	229

		—Charpy values, ft-lb—			
Test no.	*Condition*	*Plate, 70° F*	*Weld, 70° F*	*Plate, 60° F*	*Weld, 60° F*
1	As-received	113.0–101.1	30.2	10.3– 14.7	12.4
2	S.R. 1075—4 hr	120.8–124.7	18.0	22.0– 22.0	10.3
3	Q. 1650, D. 1000	116.9–124.7	15.8	83.5–105.0	9.2
4	Q. 1650, D. 1125	145.2–132.2	22.0	143.8–132.2	15.8

Table 2—NES 70—$^3/_4$-In. Steel Plates—Butt Welded, V Groove
Hand-welded NES 70 Rod. Low-Hydrogen Flux

Test no.	Condition	Yield point, psi	Tensile strength, psi	Elongation, % 2 in.	Elongation, % 4 in.	Break	Brinell
1	As-welded	93,900	107,300	18.	12	Plate	228
2	S.R. 1100—4 hr.	85,300	99,600	23.	14.5	Plate	217
3	Q. 1650, D. 1000	128,800	138,200	9.5	7.5	Plate	302
4	Q. 1650, D. 1125	106,000	117,600	23.0	14.0	Plate	269

Weld Zone Hardness As-Welded: Plate, 96 Rockwell B; Weld, 101/103 Rockwell B; Zone, 97/101 Rockwell B

Test no.	Condition	Charpy values, ft-lb: Room temp., 70° F		Charpy values, ft-lb: 60° F		
1	As-welded	24.4	45.0	6.3	6.3	6.3
2	S.R. 1100—4 hr	97.2–103.2	25.9	13.5	6.3	10.3
3	Q. 1650, D. 1000	85.6– 79.8	23.0	68.8	41.6	12.4
4	Q. 1650, D. 1125	122.5–114.9	35.0	134.2	120.8	14.7

and tempered condition the product is very tough as low as −60° F.

Recently in heat treating weldments by quenching in water and drawing at 1100° F we had great difficulty in a lower hardenability in the weld metal when using the standard 0.50 moly rod with low-hydrogen flux on an automatic submerged-arc weld, butt welding $^3/_4$-in. plate. We finally rolled up some welding rod from an ingot of one of these heats of steel and found the answer to the problem. The self-type rod with low-hydrogen flux heat treated to almost the same Brinell number as the plate. Rod of this analysis is being coated for hand welding.

Table 3—Check Chemistry on $^7/_{32}$-In. Round Welding Rod

C	0.146
Mn	0.54
P	0.010
S	0.023
Ni	1.73
Cu	1.15
Mo	0.26

Tables 1, 2 and 3 show the physical properties of plates and welds in various gages and treatments.

Twinarc Submerged Arc Welding

Twinarc welding is the use of two small diameter electrodes in place of one larger electrode in a single submerged-arc welding head

by Theodore Ashton

TWINARC welding is a method of applying the submerged arc welding process. Its successful use is significantly reducing manufacturing costs. Its success results from a fundamental simplicity of equipment and an ability to produce high quality welds at speeds on the order of 50 percent faster than those normally achieved with the submerged arc process. The following information is presented to help users of welding determine whether or not the Twinarc process can obtain these benefits in their particular applications.

The presentation of this information will be to first explain what Twinarc welding is, the equipment that is needed and how it is used. Then will follow a discussion of some of the advantages and limitations. At the conclusion, there are pictures of applications on which the Twinarc can be effectively used.

Twinarc welding is the use of two small diameter electrodes in place of one larger electrode in a single, submerged-arc welding head. That is, instead of feeding just one $^5/_{32}$ or $^7/_{32}$ electrode, two smaller electrodes are fed with just one drive roll, one feed motor and one arc voltage control system. These smaller electrodes are normally pairs of either $^1/_8$-, $^3/_{32}$- or $^5/_{64}$-in. electrodes. Both of the smaller electrodes are fed at the same rate and take their welding current from the same contact jaws. This welding current which is obtained from a common source, automatically divides between the two electrodes. As the two electrodes are fed into the arc zone, two separate and distinct arcs are

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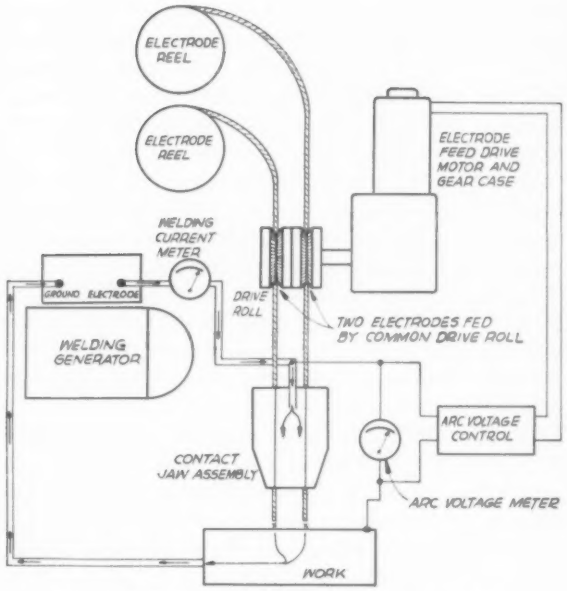

Fig. 1 Schematic diagram for Twinarc welding

formed, but since the spacing between the electrodes normally only varies from $^3/_8$ to $^5/_8$ of an inch, the two arcs are operating in the same molten pool. Due to this closeness of the arcs, there is a definite interaction between them. It is this relationship which provides the advantages of Twinarc over single arc welding.

Before these advantages are discussed, the equipment will be described so that it can be more easily understood what the process is and how it is applied.

The equipment used for Twinarc welding is unique in its simplicity. Most submerged arc welding heads can be quickly converted into heads suitable for Twinarc welding. The basic equipment components needed are shown in the schematic illustration, Fig. 1. This diagram shows the two electrodes being fed by the common drive roll through the contact jaws and into the arc. A single-arc voltage control governs the speed of the drive motor so that the electrodes are fed in at the proper speed. Since the welding current divides between the two electrodes as required, it is only necessary to read the total welding current used.

The actual changes and additions in equipment to convert standard heads for Twinarc welding are:

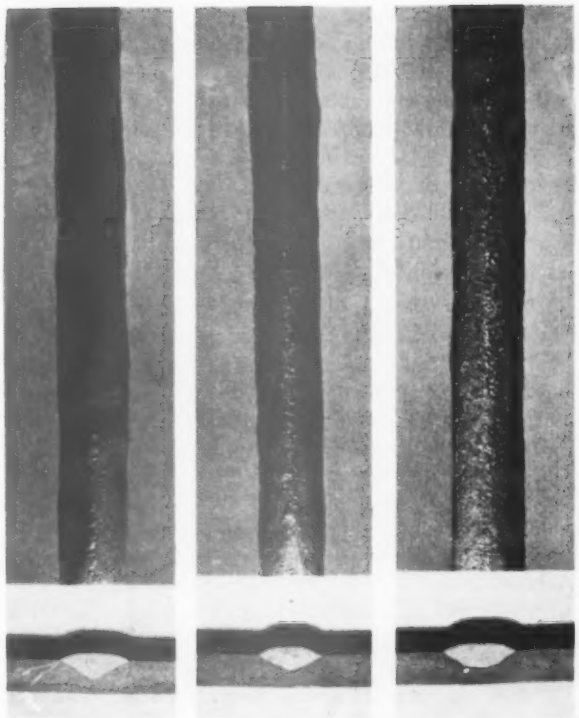

Fig. 2 The effect of electrode position on bead shape. Procedure for the beads was the same except that in one the electrodes were side by side (extreme right), skewed (center) and in line (left)

1. A second electrode reel.
2. A second drive roll.
3. A new idle roll that will give a uniform pressure on the two electrodes.
4. New guide tubes to guide the two electrodes to and from the drive rolls.
5. A nozzle with a double contact so that the current can be fed uniformly into both electrodes. This nozzle is constructed so that the electrodes can be set at different angles with respect to the seam.

In some cases it is also necessary to install additional generators to obtain full advantage of the Twinarc. The reason for this is that the most advantageous current range of the Twinarc when using $^5/_{64}$- through $^1/_8$-in. electrode is from 600 to 1500 amp. It should be

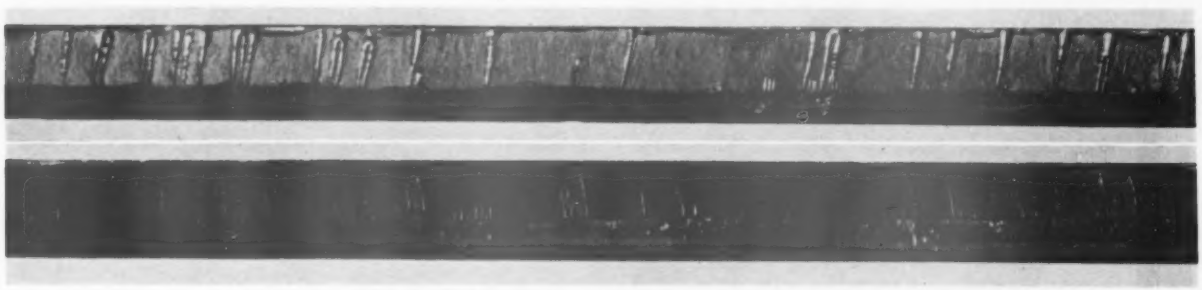

Fig. 3 Twinarc improves weld quality. Both beads were welded through a thin film of oil. Top bead is single arc, bottom bead is Twinarc. Twinarc reduced porosity and increased travel speed 30%

noted here that for the most stable arc and uniform bead, it is best to keep the current density on the electrodes above 60,000 amp per square inch. That is, with currents of from 600 to 1000 use $^{4}/_{64}$-in. electrodes, from 800 to 1400 amp, $^{3}/_{32}$-in. electrodes and from 1400 to 1500 amp, $^{1}/_{8}$-in. electrode. These are not meant to be strict ranges, only guides.

Although there is only one control each for the current arc voltage and travel speed, there are two new procedural variations which are not present in single arc welding. These are the position of the two electrodes with respect to the seam and the distance between the two electrodes.

Even though the Twinarc equipment is designed so that the two electrodes can be placed at any angle with respect to the seam, there are only three positions which are normally used. In all three cases both of the electrodes are operated perpendicular to the plate. Under these conditions one electrode can be directly behind the other with respect to travel. This is referred to as "in line" welding. Should the two electrodes be side by side, straddling the seam, it is referred to as "side-by-side" welding. The third position, or "skewed" welding, includes all positions in which a line between the two electrodes forms an angle with the seam other than 0 deg (which is "in line") and 90 deg (which is "side-by-side"). This angle will seldom be more than 10 deg on either side of the "in line" position.

By referring to Fig. 2, the effect of these three welding positions on the bead shape can be seen. The procedure of all three beads was 1000 amp, 35 v, 24 ipm, positive polarity and a distance between the two electrodes of $^{3}/_{8}$ of an inch. Although the bead width and penetration are almost equals with this particular procedure, such is not always the case. Later an explanation of how the penetration can be varied by changing the distance between the electrodes will be given. Surprisingly, the rotation of the nozzle for "side-by-side" welding, even with the wider spacing, does not have as much effect on bead width as might be expected.

Of the three above-mentioned positions, the one most often used for butt and fillet welding is the "in line" position. Under these circumstances, the penetration will be at maximum while obtaining the most uniform bead edges and the highest travel speed. When using the smaller electrodes, namely $^{5}/_{61}$ or $^{3}/_{32}$, it is sometimes advantageous to operate in the "skewed" position. This will give a slightly wider bead than that obtained with the "in line" position, and the reduction in penetration is nil. There is, however, one disadvantage to the "skewed" position in that it has a tendency

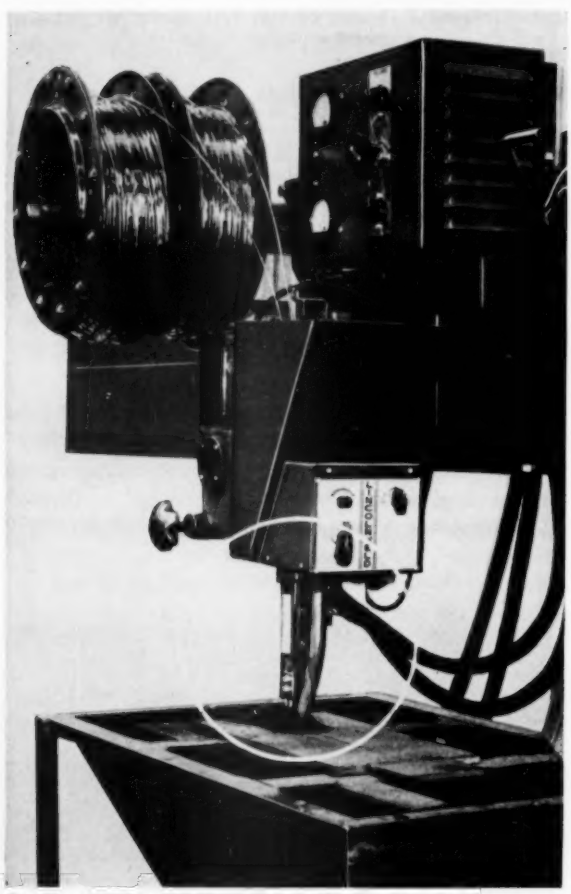

Fig. 4 A typical Twinarc setup illustrating the simplicity of the equipment

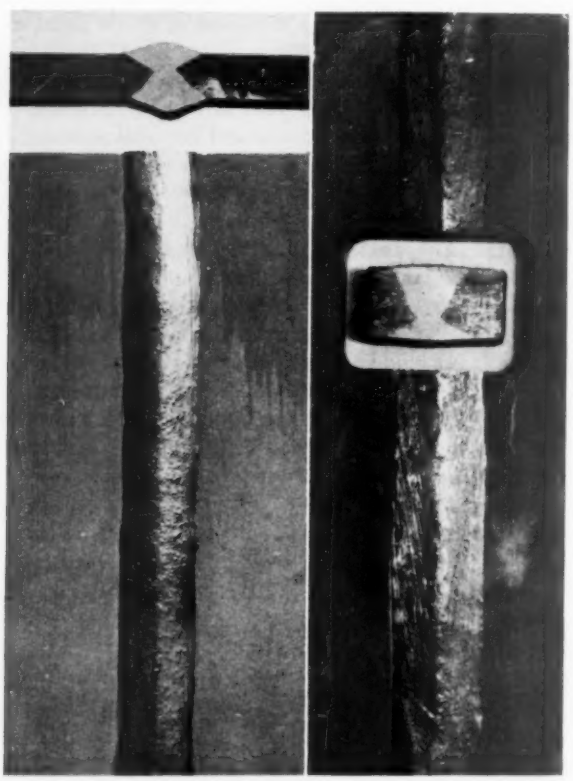

Fig. 5 Shows a square-edge butt joint on a $^{1}/_{2}$-in. plate. First pass 1000 amp, 35 v, 35 ipm, $2^{1}/_{32}$-in. electrodes spaced at $^{1}/_{2}$ in. and in line. Second pass 1300 amp, 40 v, 40 ipm and two $^{3}/_{32}$-in. electrodes spaced $^{1}/_{2}$ in. and in line

Fig. 6 Butt joint on 1-in. plate

for undercut on the side of the trailing electrode. In some cases it might be necessary to reduce the travel speed to elminate this undercut.

One point which should be mentioned is that if the electrodes are operated in the "skewed" position, it is important to let the front electrode favor the seam. The reason for this is that the arc of the second electrode has a tendency to be attracted to the hot metal deposited by the front arc; hence, the center of the bead will be nearly in line with the front electrode.

The last, or "side-by-side" position, has two principal uses. The first is for hard-surfacing applications where minimum penetration and wide flat beads are required. When the Twinarc is used for hard surfacing in conjunction with an agglomerated hard surfacing flux, it is possible to obtain a wide, smooth, uniform and tough abrasion-resistant deposit at a considerable cost reduction over previous methods.

The second use for the Twinarc with the electrodes in the "side-by-side" position is for poor fit-up joints or special applications where it is necessary to tie together two spaced edges. The advantage of the Twinarc process for this type of welding is that the arc's force is directed on both sides of the seam and not in the center of the seam as with single arc. Since the arc's force is spread over the whole bead width, penetration is decreased and the tendency for burn through is minimized. The Twinarc process is not a cure-all for poor fit-up, but it will help considerably if precautions are taken so that the molten metal and flux cannot run through the gap.

The distance between the electrodes is more difficult to establish in a definite procedure than is the angle of rotation. Some general rules can be stated but even with these rules, it is advisable to do some testing on the individual job until the desired bead shape and penetration are achieved. The reason for this is attributed to the variations in joint preparation, plate condition, flux used, arc blow conditions, etc.

The usual range of electrode spacing is at some point between $^3/_8$ and $^5/_8$ of an inch. When welding with the electrodes "in line" the following statements hold true: The narrow spacing is used to obtain a more stable arc and uniform bead at low welding currents and high travel speeds. As the welding currents increase and the speeds decrease, the distance between the electrodes should be made greater. In so doing, the penetration will be more for a given speed and current. If, however, the distance is increased too much, the arc will become unstable and poor bead edges will result.

When welding with the electrodes "side-by-side" the narrow electrode spacing is used at both high and low currents. If a greater distance is used (unless speeds are low) the penetration will be greatly diminished. It is even possible to obtain two beads side by side if the center distance is increased too much or if the travel speed is high.

It is obvious that the reduction in penetration mentioned above is the proper condition for hard surfacing. Therefore, when doing hard surfacing work, it is best to use the widest distance possible between the

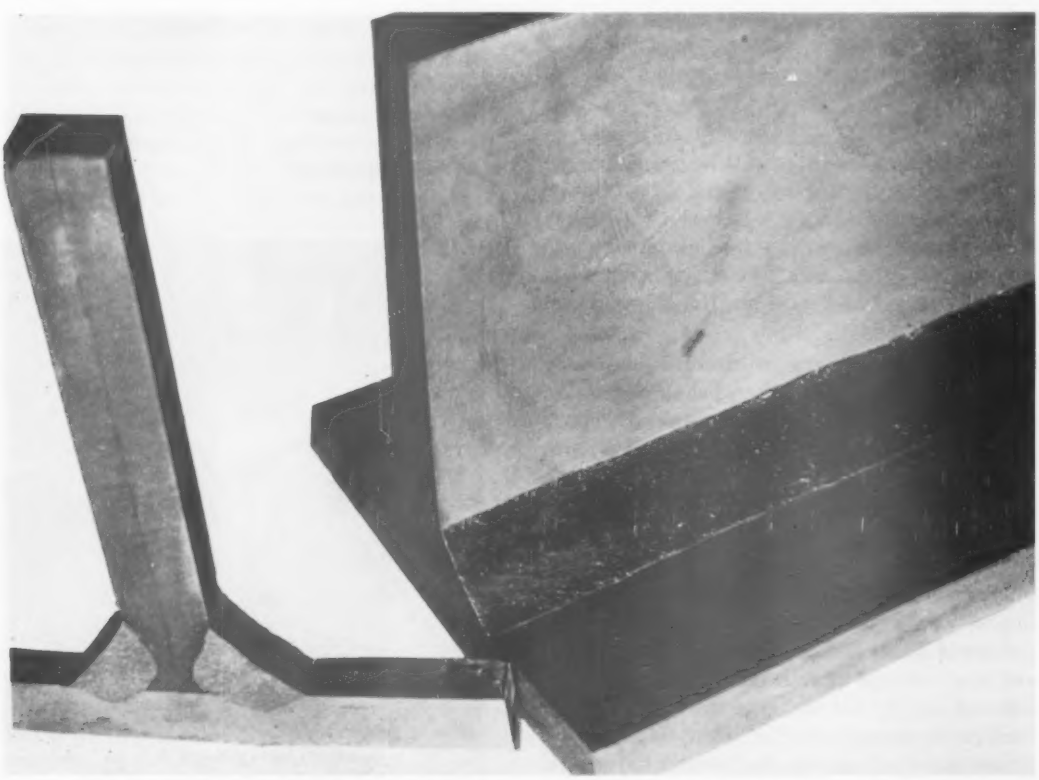

Fig. 7 Shows fillet weld on $^3/_4$-in. plate. Leg size is $^7/_8$ of an inch. Speed, 15 ipm

electrodes and still be able to obtain a single bead. The importance of the reduced penetration, and therefore dilution, by the use of the Twinarc is that the welding current can be increased over that normally used by a single electrode. Since the current can be increased, it is also possible to increase the welding travel speed and still obtain a bead of equivalent abrasion resistance as that made with a single electrode.

One other benefit of the Twinarc hard-surfacing bead is that the top of the bead is flat compared to the humped up or convex bead obtained from a single arc.

To be able to effectively use the Twinarc it is necessary to know some of its advantages and limitations. With this information a sensible analysis can then be made to determine on what jobs the Twinarc might be of value.

Perhaps the first and most important advantage of the Twinarc is its ability, when properly used, to make welds of higher quality than those made with a single arc. An example of the Twinarc's ability to improve the quality is illustrated in Fig. 3. Two beads are shown. The top bead was made with $^{7}/_{32}$-in. electrode at 700 amp, 35 v at 27 ipm. The bottom bead was made with two $^{3}/_{32}$-in. electrodes at 950 amp, 35 v, 35 ipm, a distance between electrodes of $^{1}/_{2}$ in. and "in line." Before welding, the plate edges of the above joints had a thin film of oil such as might be found in the shop. Admittedly, this is a severe test, but it is obvious that the Twinarc has reduced the porosity, and yet the travel speed with Twinarc was 30% greater. In addition to controlled laboratory tests as shown above, reports from the field mention applications that are getting higher travel speeds than can be made with single arc and are still maintaining high quality X-ray standards.

Another advantage of the Twinarc is its ability to make welds at speeds which average 150% above single arc speeds. This increased speed, aside from the lower labor costs, has a special advantage in that it will reduce the amount of plate distortion. One example where this minimizing of distortion is especially important is that of welding long box beams and other structural shapes.

When doing hard-surfacing work or filling deep grooves on prepared joints, the Twinarc has an additional benefit in that the melt-off rates are higher. For example, the melt-off rate of two $^{1}/_{8}$-in. electrodes "in line" is approximately 18% higher than with a $^{7}/_{32}$-in. electrode at the same welding current. If the two $^{1}/_{8}$-in. electrodes are in the "side-by-side" position the melt-off rate will be 9% higher.

Certainly one of the greatest assets of this new process is its simplicity of equipment and usage. A typical Twinarc setup is illustrated in Fig. 4. It is a piece of equipment that can be purchased in kit form at a reasonable cost and be assembled to many of the submerged arc heads already in the field. This can be done without major changes in the present fixtures or setups.

The Twinarc also has certain limitations. One of these is the lack of penetration which is obtained on heavy plate welding with prepared edges. On V joints which are deeper than $^{5}/_{8}$ of an inch it is necessary to keep the speed above 15 ipm to get any appreciable penetration into the root. Since the top current normally used is 1500 amp, a limit is set on the maximum plate thickness that can be welded with but one pass from each side. This limit is between $1^{1}/_{4}$- and $1\ ^{1}/_{2}$-in. plate thickness. On plates thicker than this, it is necessary to use multiple passes. The procedure is to fill the groove on the first pass side with one bead if possible. This can be done at speeds as low as 7 ipm, but there will be little penetration into the root. The plate is then turned over and a pass is put in at 1400 amp, 32 v, 18 ipm. This bead will have penetration into the root of about $^{1}/_{4}$ in. and if the plate preparation is correct, should give a good overlap to insure a 100% weld. Another bead is then used to fill up the second pass side.

As plates become thinner and travel speeds go up, it is found that at speeds over 50 to 60 ipm the speed advantage of Twinarc over single arc is not so apparent. This means that for plate thicknesses under $^{1}/_{4}$ in. it is more unusual to find the advantages that make it so outstanding on the heavier materials.

When using the Twinarc on applications involving fillet welds it will sometimes be found that the average 150% speed increase of Twinarc over single arc cannot be achieved. The reason for this is that weld cracking becomes more of a problem as the travel speeds are increased. Since the speed of a single arc fillet weld is usually limited by the bead shape and appearance, it is not often that speeds get high enough for cracking to become a problem. Now that we can obtain good bead shape and appearance with Twinarc at higher speeds cracking will become a limiting factor in some cases, and so the full speed cannot be made.

Perhaps the best way to show the type of work that

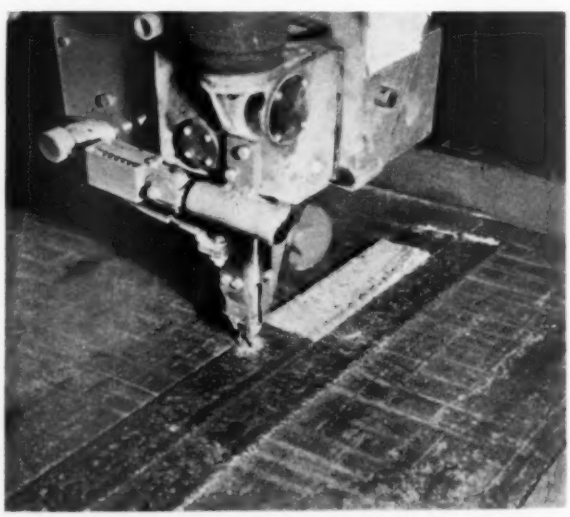

Fig. 8 A hard-surfacing bead $3^{1}/_{2}$ in. wide made with Twinarc and Spreadarc combination setup. The automatic welding head with two wires is oscillated from side to side

the Twinarc can accomplish is to illustrate actual welds which have been made in the laboratory and in the field.

Figure 5 shows a square-edged butt joint on 1/2-in. plate. The welding procedure was: first pass, 1000 amp, 35 v, 35 ipm, two 3/32-in. electrodes spaced at 1/2 in. and "in line"; second pass, 1300 amp, 40 v, 40 ipm, two 3/32-in. electrodes spaced at 1/2 in. and "in line."

Figure 6 is a picture of a prepared plate butt joint on 1-in. plate. The plate preparation on the first pass side was a 75-deg included angle V, 3/8 in. deep. A 90-deg included angle V, 7/16 in. deep was used on the second pass side. The welding procedure was: first pass, 1150 amp, 34v, 20 ipm, two 3/32-in. electrodes spaced at 5/8 in. and "in line"; second pass, 1500 amp, 33 v, 17 ipm, two 3/32-in. electrodes spaced at 5/8 in. and "in line." Good overlap is shown with almost flush beads on both sides.

Figure 7 shows a positioned fillet weld on 3/4-in. plate. Fillet leg size is 7/8 in. The welding procedure was 1500 amp, 35 v, 15 ipm, two 1/8-in. electrodes spaced at 1/2 in. and "side-by-side."

In the next application the Twinarc is being used for hard surfacing with mild steel electrodes and agglomerated fluxes. In some of these applications the Twinarc is used in conjunction with a new piece of equipment now being developed. This new equipment is called Spreadarc, and its function is to swing the electrode back and forth across the seam or perpendicular to the direction of travel so that the bead width can be increased to above 3 1/2 in. The Spreadarc can be used either with a single arc or the Twinarc, but with the Spreadarc-Twinarc combination, a more abrasion-resistant bead can be made at higher speeds.

Figure 8 illustrates a hard-surfacing bead made with Spreadarc-Twinarc combination, bead width 3 1/2 in. The welding procedure was: 700 amp., 32 v, 5 ipm, two 1/8-in. electrodes spaced at 5/8 in. and "side-by-side," negative polarity, 18 to 20 oscillations per minute.

Figure 9 is a picture of a Twinarc hard-surfacing bead made without the Spreadarc on high-carbon steel; the bead width is 1 in. The welding procedure was:

Fig. 9 A Twinarc hard-surfacing bead made on high-carbon steel

Fig. 10 A hard-surfacing bead deposited with the Twinarc Spreadarc combination on the tip of a shovel point

600 amp, 33 v, 18 ipm, two 1/8-in. electrodes spaced at 1/2 in. and "side-by-side," negative polarity.

Figure 10 shows a hard-surfacing bead on the tip of a shovel point, bead width is 3 in. The welding procedure was: 730 amp, 32 v, 5 ipm, two 1/8-in. electrodes spaced at 5/8 in. and "side-by-side," negative polarity, 22 oscillations per minute.

These are only a few of the many applications suitable for Twinarc welding. As the equipment finds more use in the field, new applications and information will be obtained so that more people can obtain high-quality weld at reduced costs.

(*Continued from page 323*)

tion. If a series of well-developed and properly supervised operator's qualification and requalification tests could be developed, and a program of adequate training and control of such tests be maintained, then very definitely it would go a long way toward assuring good quality welds, and perhaps even to the extent that Mr. Bland explains it in his discussion.

Unfortunately, and all of us who have ever been involved in the business of welded fabrication and such qualifications know, tests of that kind are not necessarily the answer to quality problems. Too many such tests are given to operators in order to show qualification, rather than to show the operator's ability. We have all heard of cases where qualification tests have been given operators several times, after each succeeding test has failed, to a point where finally one has passed, and the operator has then been considered qualified. Conditions such as these hurt the idea which Mr. Bland advocates; that of the importance of qualification and requalification of operators. As far as the rest of Mr. Bland's discussion is concerned, it is well taken, and the authors are grateful for his kind words.

D-C Welders—Rectifiers or Motor Generator Sets?

A Comparison of the static and dynamic performance characteristic of rectifier welders and motor generator sets

by S. Oestreicher

INCREASING numbers of d-c rectifier welders are used; therefore, a comparison of the operating characteristics of motor generator sets and rectifier machines might be of interest.

Basically, a d-c rectifier welder is a transformer device. Its appearance (Fig. 1) emphasizes the resemblance to the well-known transformer welder.

A three-phase transformer changes the line voltage to the voltage required for the desired open-circuit voltage (Fig. 2). The secondary of the transformer is connected to a reactor for output control. The controlled a-c output is then connected to rectifier banks; in this way the d-c power is made available without the conversion of electrical energy into mechanical energy and back to electrical energy as is the case with a motor generator set.

The connection diagram shows output control by means of a saturable reactor. The premagnetization of a reactor core/cores is changed by means of a d-c control winding. In this way the reactance (resistance against flow of a-c current) of the reactor winding is changed. No premagnetization gives minimum output and maximum premagnetization allows maximum output.

Figure 3 illustrates design details of a d-c rectifier welder. The main components are marked the same as on the connection diagram (Fig. 2).

Any type of output control which is used on single-phase a-c transformer welders can also be adapted to d-c rectifier welders. Instead of changing the magnetic properties of the reactor electrically, a variable air gap can be introduced. With this arrangement the largest air gap provides maximum output while the minimum air gap corresponds to the minimum control setting. Figure 4 shows details of such a machine. The three-legged reactor core is moved by means of a screw arrangement; thereby, the air gap between the upper and lower core section is varied. An interesting detail of this design is the use of the secondary of the transformer winding as part of the reactor winding at the same time. Figure 5 gives a "close-up" of this transformer-reactor arrangement. The transformer core is shown while the reactor core has been removed.

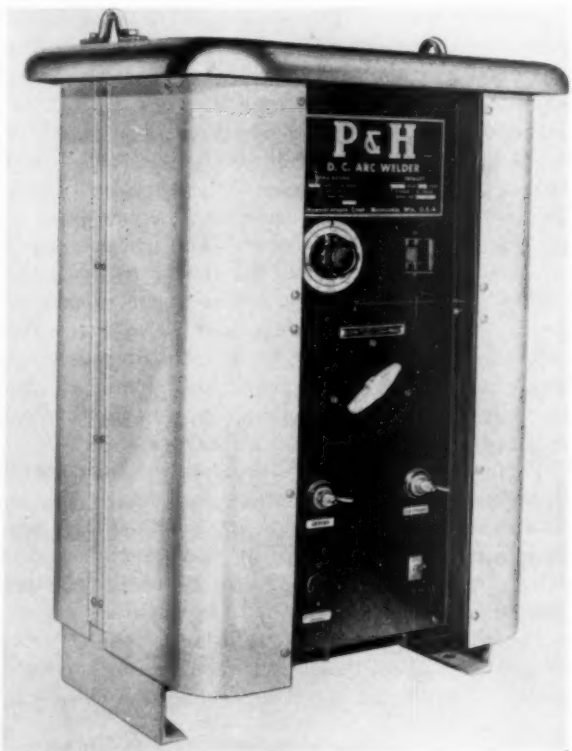

Figure 1

Other designs of d-c rectifier welders vary the distance between primary and secondary windings of the three-phase transformer for output regulation.

The static volt-ampere curves (Fig. 6) of rectifier welders also resemble those of a-c transformer welders. In contrast to most motor generator sets, generally no control of the open-circuit voltage is provided. Wide welding ranges are easily achieved as indicated by these curves.

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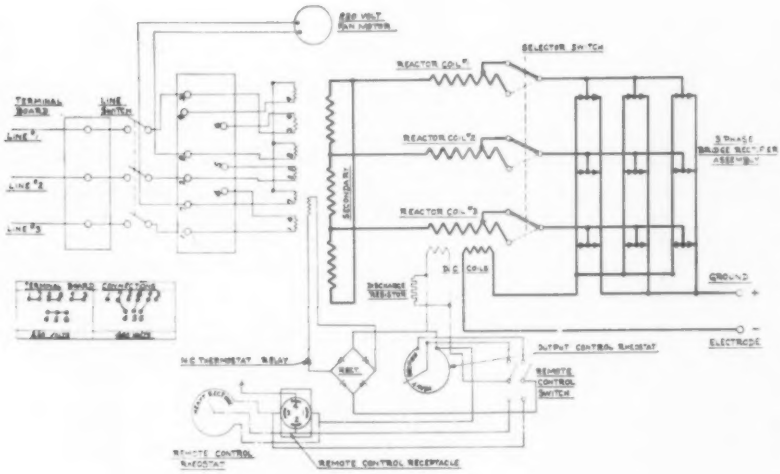


Figure 2

The "dynamic characteristic," i.e., the performance under fast varying load conditions, indicates the main difference between performance of motor generator sets and rectifier welders. The difference can best be shown by oscillograms which record the voltage and current variations when the machines are switched from "open" to "short" to "load." Although a resistance load is used for loading the welder, it is often assumed that this arrangement resembles the actual arc striking sequence.

Figure 7 indicates that the short circuit current of a d-c welding generator rises to a value above the final amperage before receding to the value shown on the static volt-ampere curve. Switching from "short" to "load" indicates a dip in current before gradually approaching the value corresponding to the control setting. The voltage, after an initial overshoot, follows the current curve rather closely. The advantages and disadvantages of these "overshoots" and "underrides," as well as their permissible values and duration, have been discussed in many papers. Sometimes they have been included in performance specifications. Discussions on the performance of welding machines, as established by oscillograms with resistance load, have been of considerable value in improving the design of welding generators. However, in some cases it was forgotten that this approach was only a convenience and that the interpretation did not necessarily apply to actual welding performance.

The arc voltage and welding current of a d-c generator under actual welding conditions are shown in Fig. 8. The output varies between welding load and "shorts" or "partial shorts." No "underrides" of current and hardly any "overshoots" of voltage can be observed. The current "overshoots" (when a short occurs) are rather pronounced. The moment the welding arc is re-established, the full arc voltage is restored. In fact, this voltage recovery is so fast that it is doubtful any

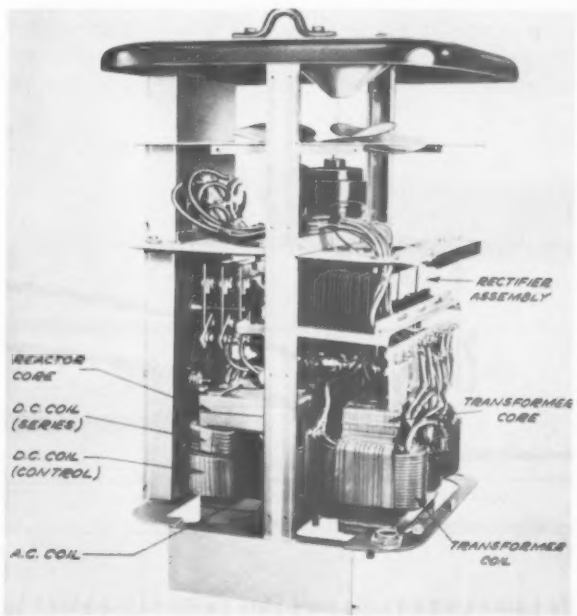
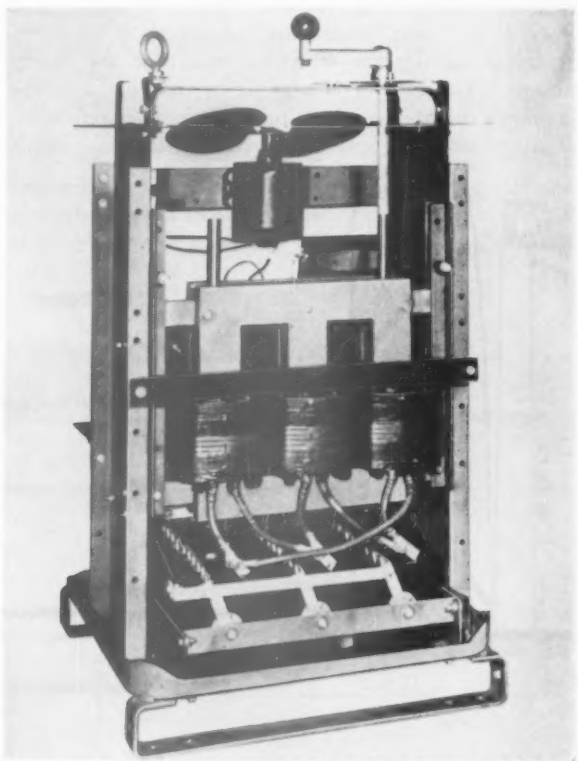


Figure 3



Courtesy Westinghouse Electric Corp.

Figure 4

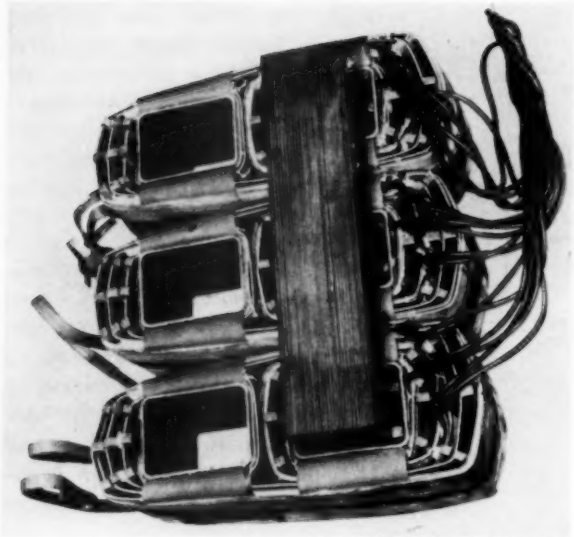


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Figure 5

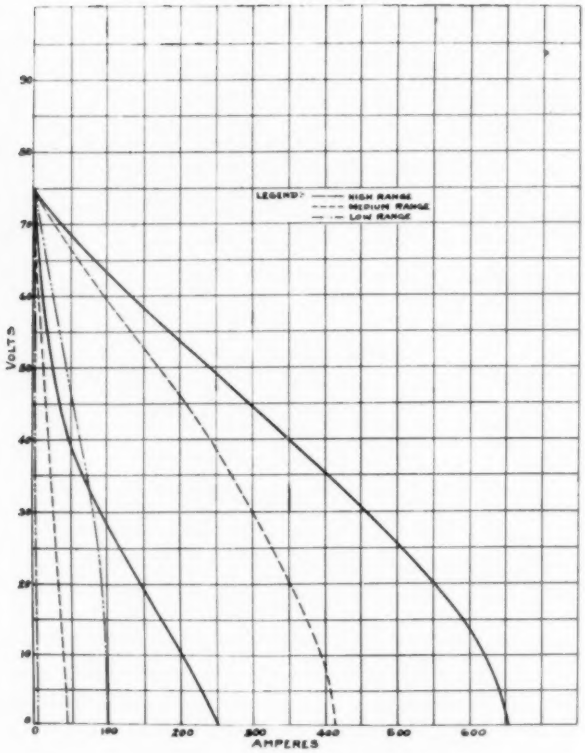

Figure 6

variation in excitation could act or react with the required speed, for even the best arrangements have limitations due to their time constants. The oscillogram indicates that the welding circuit, either within the generator or by means of added outside reactors, must have sufficient impedance to allow the current change itself to induce the required voltage.

The oscillogram (Fig. 9) shows the performance of a rectifier welder with variable resistance load. The "overshoots" and "underrides" observed on the corresponding oscillogram of a d-c generator are nearly absent. The rate of change in the rectifier machine is mainly dictated by the supply line and, therefore, instantaneous for all practical purposes. If the a-c ripple is neglected, the performance, not the efficiency, rather closely resembles that of a constant potential machine with output regulation by means of resistor banks.

The operators of the early rectifier welding machines reported that in deep groove work the tendency of freezing the electrodes to the work was more pronounced than on motor generator sets. Therefore, devices were introduced to duplicate the inherent

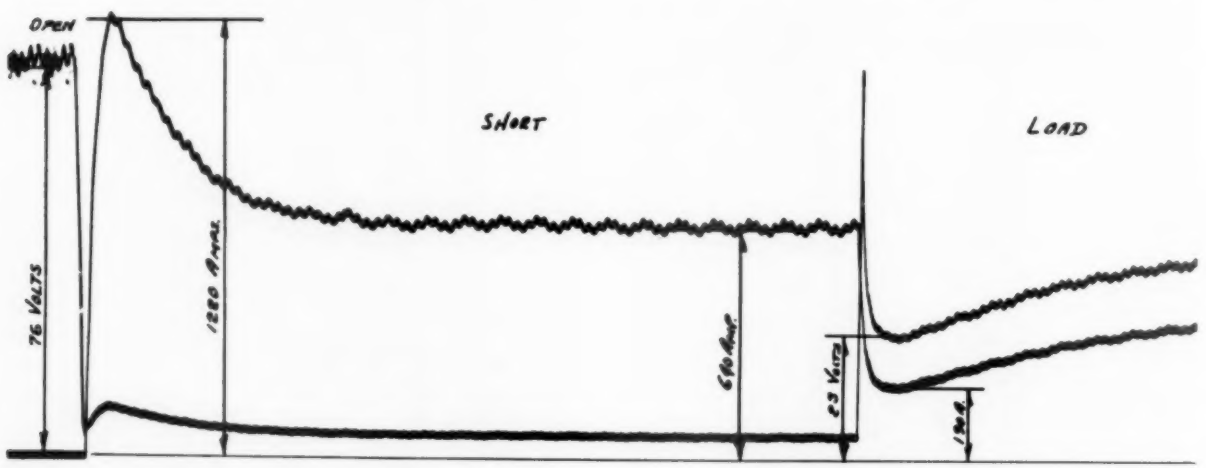

Figure 7

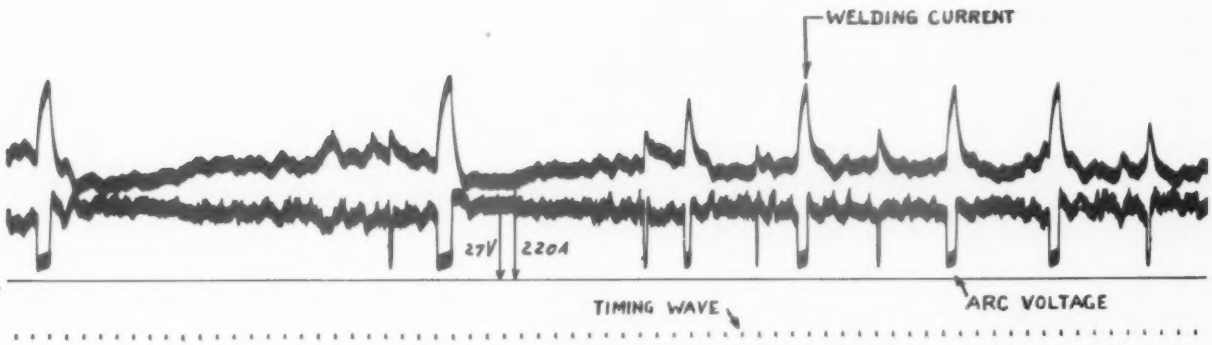

Figure 8

current overshoots of d-c welding generators. The "arc-drive" circuit of a well-known design provides additional welding current by means of an auxiliary circuit which becomes operative whenever the arc voltage falls below a given value—about 10 to 15 v. Generally, machines with saturable reactor control use a second control winding in series with the welding lead. This "feed-back" also gives an increase in short circuit current and in this way has overcome the few instances of operator resistance.

The connection diagram (Fig. 2), as previously indicated, shows the circuit used in a rectifier welder with saturable reactor control. Modifications in the control circuit allow the choice of any value of short circuit current for any desired time. Furthermore, the remote control feature enables the user to preselect any desired performance sequence for automatic work or similar applications. The normally closed thermostat shown on the diagram is located in close proximity to the rectifier plates.

The heat capacity of the rectifier plates is low in comparison to that of other major components. Their temperatures, therefore, follow the load variations comparatively fast. In order to protect them against destructive high temperatures, the thermostat opens the control circuit as soon as a predetermined temperature is reached. Without premagnetization only the minimum output of the selected operating range of the machine is available. After the machine has cooled off sufficiently, the thermostat closes the control circuit and normal operating conditions are automatically restored. Overloads will cause service interruptions of short duration only because the cooling fan remains in operation.

The graph (Fig. 10) shows the heating and cooling of a rectifier stack and of the a-c reactor winding. Two conditions are shown. First, the machine terminals were shorted with the control at the 200-amp position followed by the control in the maximum output position. The corresponding load currents were approximately 300 and 385 amp. It is evident that the thermal protection is adequate even for such extreme load conditions.

The internal resistance of rectifier plates decreases with increasing temperature. This property practically compensates for the reduction of output that must be expected from other components—as transformers, reactors and control circuits—with increasing operating temperature. Therefore, the output of a rectifier welder will usually be more stable than that of a motor generator set. Figure 11 shows the stability in output of both types of machines for comparable conditions.

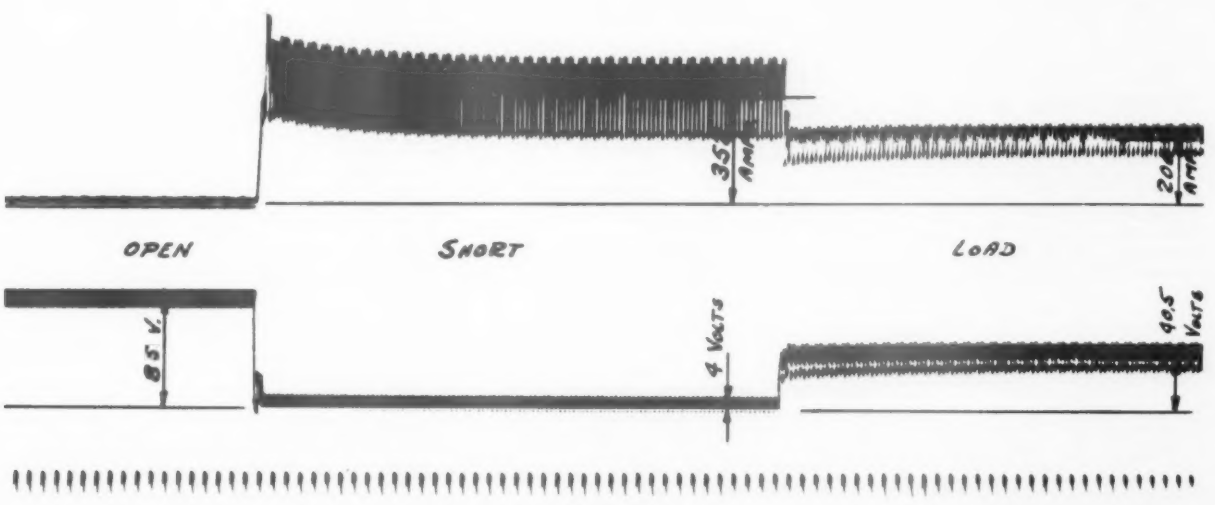

Figure 9

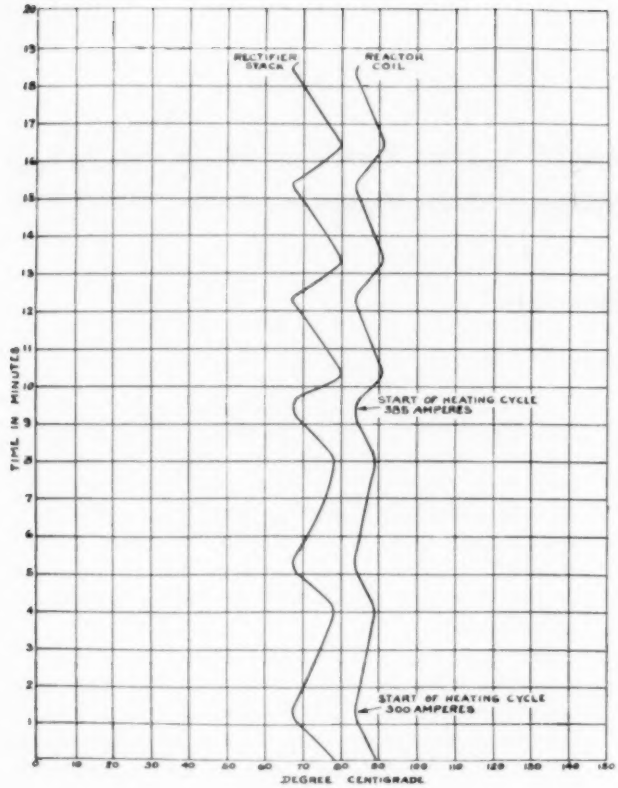

Figure 10

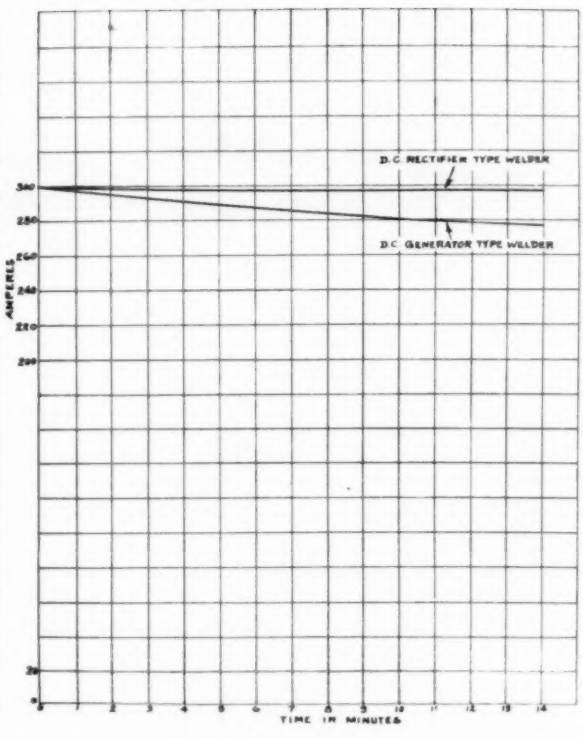

Figure 11

The welders worked against a resistance load, the output voltage was kept constant by varying the load resistance and the control setting was not changed during the test. The change of output current of the motor generator set is appreciable, while the output of the rectifier welder is practically constant.

Generally, the operating efficiency of rectifier welders is somewhat higher than that of a corresponding motor generator set. Comparable operating costs are tabulated in Table 1.

After several years of field experience, it can be stated that rectifier machines have proved themselves in many applications where formerly d-c generators have been the only choice.

Table 1—Operating Cost Comparison

	300-amp motor generator set	*300-amp rectifier welder*	*300-amp transformer welder*
Full load			
Current	60 amp @ 220 v	60 amp @ 220 v	91 amp @ 220 v
Watts	19,400	18,460	15,200
No load			
Current	17 amp @ 220 v	3.4 amp @ 220 v	22 amp @ 220 v
Watts	3,700	640	750
Power factor (F. L.)	85%	80%	75%
Efficiency (F. L.)	61.5%	65%	80%
Whr/0.6 hr—full load	11,630 w/hr	11,080 w/hr	9120 w/hr
Whr/0.4 hr—no load	1,480 w/hr	256 w/hr	300 w/hr
Total whr/hr, 60% duty cycle	13,110 w/hr	11,336 w/hr	9420 w/hr
Total kwhr/hr, 60% duty cycle	13.11 kw/hr	11.336 kw/hr	9.42 kw/hr
Total kwhr per 8-hr day	105 kw	91 kw	75.4 kw
Cost/kwhr (use local rate)	$ 0.015	$ 0.015	$ 0.015
Operating cost per 8 hr	$ 1.57	$ 1.36	$ 1.13

Carbon-Steel Electrodes for Use with Inert Gas Shields

A study of the properties of weld deposits from an electrode for production use in the welding of carbon steel by the inert-gas-shielded metal-arc process. The use of a fully killed steel electrode seems indicated

by Harry C. Cook and Gilbert R. Rothschild

INTRODUCTION

INERT-gas-shielded arc welding with a consumable electrode is used extensively today for joining aluminum alloys, copper alloys, and stainless steel. This process has competed with older procedures used for these materials, and carved its niche in the roster of available welding methods. For aluminum and copper alloys, the new technique has provided, on many occasions, weld quality and economy superior to that available with other methods; and in some cases, it was the only way of making the weld. For stainless steel, it has often proved the most economical because of its efficient use of an expensive filler material.

The welding of carbon steel by this method has not been completely evaluated even though it has been used in production for a year. Use of the new process for welding carbon steel has been made for one or more of the following reasons: (1) maximum economy was achieved, (2) needed visibility of the operation was obtained or (3) a unique characteristic of joint design or plate material required the inert-gas process.

Competition among the various welding processes is more intense in carbon steel than in other materials. Two good methods, shielded metal-arc welding and submerged arc welding, have been available for some time; and consequently, the cost of welding carbon steel is low and the quality of welding is high. Because of this, the establishment of inert-gas-shielded arc welding with consumable electrode as a recognized method for the fabrication of carbon steel has proceeded at a slower pace than that attained with other materials.

When inert-gas welding was first used for carbon steel, the selection of electrode compositions was based on the weld-deposit analyses obtained with the older, well-established processes. These deposits generally have a composition lying within the following range:

C, %	0.06–0.20
Mn, %	0.40–2.00
Si, %	0.02–0.30
S, %	0.03 max
P, %	0.03 max

For shielded-metal arc welding the manganese in the deposit of E60XX electrodes seldom exceeds 0.60%.

The first three wires used for production and the properties obtained with them are shown in Table 1. The wires are listed in the order of their introduction.

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Table 1—Weld Properties of Some Mild Steel Electrodes Used for Inert-Gas-Shielded Arc Welding

Electrode	*Composition, %* C	Mn	Si	S	P	*Yield strength, psi*	*Ultimate strength, psi*	*% elongation in 2 in.*
3204*	0.18	1.25	0.24	0.027	0.013	72,500	86,500	25
A615*	0.18	1.10	0.17	0.023	0.023	55,000	74,000	27
A650*	0.08	1.31	0.29	0.022	0.012	66,000	75,000	23
E6010†	..	..	..	..	..	52,000 to 58,000	62,000 to 70,000	22 to 28
E6015†	..	..	..	..	..	60,000 to 71,000	75,000 to 82,000	23 to 30

* Argon plus 1% oxygen. Reverse-polarity direct current.
† Shielded metal arc welding.

Typical results for covered metal electrodes are listed for comparison.

To obtain satisfactory soundness, it is necessary to use a killed steel for the electrode. Rimmed steel electrodes produce excessive porosity. Porosity with killed steel electrodes decreases as the amount of deoxidizer increases, but complete absence of holes cannot be guaranteed by providing large amounts of deoxidizer.

Deoxidizers other than manganese and silicon, such as aluminum, zirconium and titanium, are available, and a brief study was made to determine whether an improvement in deoxidation practice could be made using these materials. Eight wires having various amounts of these deoxidizers were tested with reverse-polarity direct current. From the results of these tests there appeared to be no advantage in using aluminum, titanium or zirconium in preference to silicon. Porosity decreased as the manganese and silicon content was increased until 0.25% silicon and 0.60% manganese were reached. However, excessive porosity was encountered with this amount of manganese and silicon when straight polarity was used with a shielding gas of 95% argon and 5% oxygen.

The selection of an electrode composition for inert-gas-shielded arc welding presents a problem different from the one encountered in shielded metal-arc or submerged arc welding. The flux used in these latter two processes provides control over wetting of the weld metal, freezing rate of the molten pool (thus influencing the escape of gas), deoxidation of the weld metal, the amount of refractory oxides remaining in the deposit, weld penetration and composition of the weld metal. For the inert-gas process, the present control of these variables is limited to the adjustment of the electrode composition, the application of emissive coatings on the electrode surface, and the modification of the shielding-gas composition. Since the shielding gas is under the control of the user, it can be seen that the electrode composition must be adjusted to operate with the various gases that may be used. Furthermore, the composition must be applicable with many welding techniques since the available range of these (current density, arc length, manipulation, etc.) is much greater in inert-gas welding than in other processes.

The selected composition must provide weld-metal mechanical properties equivalent to those established for the E60XX class of covered metal electrodes. Since there is no hydrogen in the protective atmosphere when using the inert-gas process, the electrode can be used where weld metal is required equivalent to that from an E6015 electrode.

The surface finish of the wire must be such as to permit uniform feeding, not contribute to the formation of porosity, and, if possible, to retard rusting. An exploratory test on laboratory finished wire indicated that "extra clean bright" finish would be satisfactory in all respects.

As a result of the early production trials and the aforementioned tests, a new composition was selected containing less manganese and more silicon than used heretofore. Since a low-carbon level is desirable, the manganese was decreased to maintain a reasonable manganese-to-carbon ratio and so avoid any possible need for an expensive low-carbon ferromanganese alloy addition when making the steel. The silicon was brought to a high level to assure sufficient deoxidation even under conditions extremely favorable to rimming and, particularly, to avoid excessive porosity when welding with 95% argon–5% oxygen shielding gas. There also had been some indication that the contour of straight-polarity fillet welds is improved as the silicon content of the electrode is increased.

The first large-scale commercial heat of this type, Airco A675, obtained with an extra clean bright finish, had the following analysis:

C, %	*0.13*
Mn, %	*1.10*
Si, %	*0.47*
S, %	0.022
P, %	0.022
N_2, %	0.005
Residual elements:	
Ni, %	0.02
Cr, %	0.02
V, %	0.04

An important question that remained to be answered was this: How will the weld metal properties be affected by the technique of applying this electrode? This investigation was undertaken therefore to ascertain the influence of welding technique upon weld metal properties using the A675 electrode. In addition, a brief study was made in which various types of joints were welded with plates having various surface finishes.

The main portion of this presentation will dwell on the properties of weld deposits made with the A675 mild steel electrode, the chemistry of which has just been discussed. Also to be included, will be optimum welding conditions for producing butt and fillet welds for various conditions of plate and welding position, as well as the results of tests made in accordance with the requirements of the Military Specification MIL-E-9864 for MIL-180 mild steel electrodes. A further section will present data on explosion tests.

PROCEDURE

Welding Method for Weld Metal Properties

Unrestrained butt joints were made in $^3/_4$ in., semi-killed, ASTM A285, Grade C, Flange Quality steel plate. The composition of this plate was as follows:

C, %	0.20
Mn, %	0.57
Si, %	0.18
S, %	0.04
P, %	0.021

A single-V groove was used having a 60-deg included angle, a $^1/_2$-in. root opening and a $^3/_8$-in. mild steel backing of a composition similar to the base plate. The plate bevels were prepared by oxy-acetylene cutting and grinding. The backing bar and plate surface within $^3/_4$ of an inch from the bevel were ground before welding. To insure stable arc action while welding within the groove, one inch run-on and run-off tabs were used. The interpass temperature was held at approximately 200° F except in three welds where 100° and 400° F were used.

The surface finish of this electrode was not as satisfactory as that previously obtained in the laboratory. The electrode therefore was treated at various times by several of the following methods: an electrolytic, sulfuric-acid etch; an alkaline degrease; or a phosphoric acid dip. The latter produces an iron phosphate coat which resists corrosion. The electrode also was modified by applying a small amount of an emissive agent to its surface. The action of an emissive agent will be described in the discussion of test results.

In addition to wire finish, a number of other variables were studied. They were as follows: composition of the shielding gas, power supply, current, arc voltage, manipulative technique, interpass temperature and energy input per inch of weld.

The electrode diameter, however, was fixed at $^1/_{16}$ in. It is believed that the information obtained is equally applicable to different wire sizes if the same range of current density is used. It may be expected, however, that the smaller electrode sizes may result in more oxidation losses due to the increased surface area coming in contact with the welding atmospheres as the metal passes through the arc. The larger wires, due to the greater energy associated with them, would result in deeper penetration into the previous passes, and when large passes are employed, there may be large areas of cast columnar structure occurring in the weld. This effect is apparent in the results of direct explosion tests in which samples welded with two large submerged-arc passes failed with exceptionally low impact resistance.

All of the welding done in this investigation was performed manually using a standard Model 20 Aircomatic® gun. The gun always was held at 10 to 15 deg from the vertical for both backhand and forehand welding.

Standard double-charcoal-distilled helium and welding grade argon, 99.9%, were employed for the inert shield. Argon plus 1% oxygen was obtained from cylinders containing the premixed gas, the tolerance on oxygen being ±0.2%. Carbon monoxide of 99.9% purity produced at the Air Reduction Research Laboratories was employed for the carbon monoxide mixtures. The carbon dioxide mixtures were made with the standard gaseous product made by Pure Carbonic Co.

The flow of helium, argon and argon plus oxygen mixtures was measured by metering regulators. A standard 40 cfh total flow was employed for all the argon-rich mixtures. The flow rate was increased to 100 cfh for helium-argon and CO-CO_2 mixtures, while 150 cfh were employed for the helium shield. The CO and CO_2 were metered with variable orifice flowmeters.

The current and voltage were measured with recording meters. The reported currents and voltages are the averages of the values obtained for each pass in the joint. The value of energy input was obtained by using the average current, voltage and travel speed.

Three sources of power were used. The d-c power was supplied by either a 400-amp selenium rectifier or a 600-amp motor-driven generator. These were used interchangeably since no difference between them was observed in operation. Alternating-current power with an open-circuit voltage of 75 v was obtained from a standard welding transformer of 400 amp capacity. Alternating-current power with an open-circuit voltage of 150 v was obtained from an inert-gas tungsten-arc welding transformer of 800 amp capacity.

Welding Method for Joint Properties

A number of butt and fillet welds were made with ASTM A285, Grade C, hot-rolled flange-quality steel in both the flat and horizontal positions. Three thicknesses of plate $^1/_4$, $^3/_8$ and $^1/_2$ in. were used. Welds were made on both ground surfaces and surfaces prepared by oxy-acetylene cutting. The aim of this work

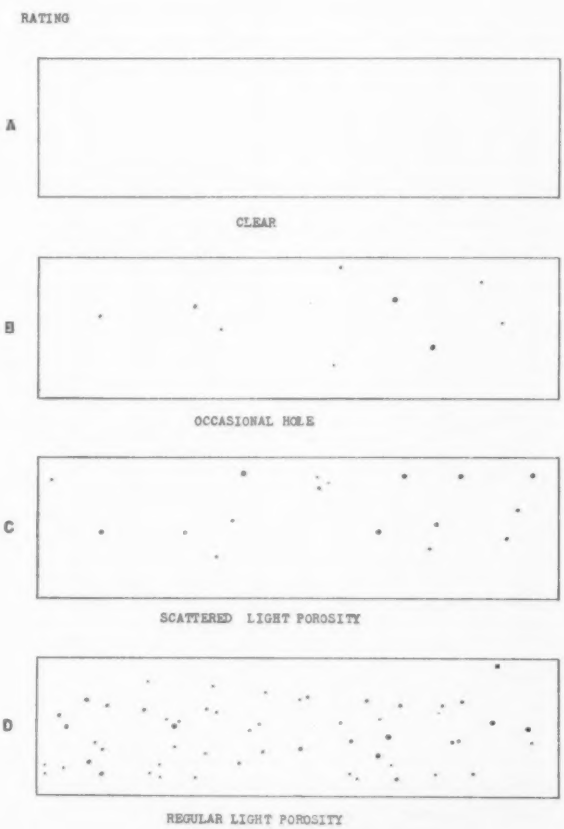


Fig. 1 Radiographic standard

(*A*) Clear. (*B*) Occasional hole. (*C*) Scattered light porosity. (*D*) Regular light porosity.

was to determine the welding conditions which most easily produce welds having the best appearance and properties. This latter was determined by X-ray examination and root and face bends for the butt welds, while the break test was used to evaluate the fillet welds.

Testing

After removal of the backing bar, all deposits were X-rayed before being machined into test specimens. The X-ray sensitivity was 1% as determined by a standard X-ray penetrameter. The standard used in rating the X-rays is shown in Fig. 1. For a weld in $^3/_4$-in plate, the D rating, regular fine porosity, would be acceptable according to the X-ray Standards for Production and Repair of Welds, Group I, Bureau of Ships.

Each of the welded joints was cut and machined into two, standard, 0.505-in. threaded-end tensile specimens and ten, 0.394 x 0.394 x 2.165 in., Charpy vee-notch impact specimens. Sections also were removed to study the macro and micro structures and to measure the Brinell hardness. Chips for chemical analysis were collected from the finish machining of the gage lengths on the tensile bars. These chips and wire from each lot received were analyzed for carbon, manganese, silicon, phosphorus and sulfur.

The weld-metal tensile specimens and impact specimens were X-rayed before testing to locate porosity in relation to the gage lengths and the notches. The nine most representative impact samples were chosen for test by this means.

RESULTS

Weld Metal Properties

Tensile Tests. The average results for two 0.505-in. tensile specimens from each of 35 welded joints are presented in Table 2. With one exception, the tensile strengths exceed 70,000 psi, and the yield strengths exceed 55,000 psi. All but six of the elongation values are greater than 22% in 2 in., and therefore, 28 deposits meet the tensile strength and ductility requirements of the AWS Filler Metal Specifications for E6010 and E6015 electrodes. Because seven deposits had 22 to 25% elongation, only 21 welds met E6020 specifications. One deposit failed to meet the E6012 specification.

Table 2—Properties of Carbon Steel Weld Metal Deposited by Aircomatic Welding

Specimen Number	Tensile Strength psi/1000	Yield Strength psi/1000	Elongation in 2 inches - %	Soundness Rating	Brinell Hardness	Composition %C	%Mn	%Si	Additions to Argon %O_2	%CO	%CO_2	Wire (1) Condition	Energy Used, Kilojoules/in./pass	Number of Passes	Current - amperes	Arc Voltage, Volts	Polarity	Remarks
4-32	86.7	73.1	28.2	D	175	0.125	0.925	0.40	Pure Argon			a	35.2	20	325	25.0	AC,75V	Fusion line porosity
4-151	85.0	68.7	28.2	A	168	0.160	0.830	0.35	5			b	36.6	12	315	31.5	R	
4-20	83.5	67.8	28.0	A	165	0.127	0.930	0.37	5			a	43.5	15	360	25.5	AC,75V	
4-12	83.0	67.5	27.8	A-	165	0.134	0.795	0.29	1			b	45.0	17	315	31.0	R	Very long arc
4-21A	81.3	67.7	31.0	C	163	0.160	0.920	0.41	80% He-20%A			b	30.0	23	300	29.0	R	
4-142	84.0	68.8	26.7	C	164	0.141	0.890	0.36	Pure Argon			a	51.0	12	350	28.0	R	
4-17	82.9	67.1	27.5	A-	166	0.150	0.810	0.32	5			b	41.0	15	310	28.0	R	
4-31	82.0	68.2	24.2	D	170	0.114	0.906	0.37	1			b	44.5	17	315	29.0	AC,150V	
4-23	83.6	70.2	23.0	C	170	0.103	0.940	0.39	1			c	38.5	18	300	25.0	R	100°F ipt
5-9	83.0	71.0	21.0	D	173	0.102	0.940	0.42	Pure Helium			d	24.3	24	320	30.0	R	% N_2 = 0.0025
5-10	83.5	70.0	19.0	C	187	0.120	0.101	0.44	Pure Argon			d	31.0	28	300	27.0	R	% N_2 = 0.0025
4-11	82.5	69.1	17.7	D-	160	0.115	0.907	0.40	1			b	36.8	17	320	24.5	R	Short Arc Produced Spatter
4-141	81.2	65.5	31.2	A	165	0.137	0.900	0.36	Pure Argon			a	61.0	9	360	25.0	S	
4-18	79.8	65.0	29.5	C-	160	0.122	0.860	0.37	5			a	44.0	12	350	26.5	S	
5-6	80.0	66.0	28.0	B+	160	0.120	0.875	0.36	1			d	41.0	18	300	26.5	R	% N_2 = 0.005
4-19	81.7	66.5	24.3	D	168	0.124	0.930	0.40	5			a	45.0	12	365	26.0	S	
4-24	78.3	64.5	25.5	B+	163	0.111	0.880	0.39	1			c	52.0	15	360	28.0	R	100°F ipt
5-29	78.5	64.7	24.7	B+	160	0.115	0.886	0.37	1			b	45.0	16	300	25.0	R	
4-21	77.5	61.6	29.0	A	160	0.126	0.900	0.33	5			a	40.0	15	360	26.5	AC,75V	
34-10	73.9	61.8	30.0	B+	160				1			d	50.0	16	300	25.5	R	
5-13	79.0	64.2	24.1	B	164	0.100	0.825	0.32	3			d	37.6	23	300	25.0	R	
5-18	78.8	65.0	22.5	B+	165	0.123	0.875	0.36	1			b	48.7	16	345	26.0	R	
5-15	77.5	63.2	28.7	C	160	0.105	0.930	0.40	1			d	41.3	16	305	24.5	R	% N_2 = 0.005
5-17	76.0	62.5	26.3	B	161	0.093	0.896	0.36	1			b	67.3	13	310	25.0	R	
5-26	73.0	58.1	27.5	A-	148	0.106	0.813	0.34	1			d	103.2	8	400	27.5	R	
5-36	71.4	58.2	32.2	A-	150	0.113	0.740	0.14	1			b	41.5	20	300	26.0	R	400°F ipt
5-12	74.0	61.3	24.0	D-	157	0.142	0.712	0.255	5			d	24.5	22	300	24.5	R	
5-25	75.0	60.8	23.5	C	145	0.102	0.880	0.36	1			d	54.8	16	400	27.5	R	
4-152	75.3	56.0	29.0	A-	142	0.165	0.610	0.24	85% CO-15% CO_2			b	63.3	11	345	42.5	R	Much spatter
5-16	72.1	56.3	26.8	B	147	0.100	0.897	0.37	1			b	73.5	9	305	25.0	R	
5-30	71.8	56.6	28.7	A	149	0.105	0.821	0.34	1			b	92.0	9	390	26.0	R	
5-14	77.5	64.2	20.5	D-	152	0.100	0.850	0.30	3			d	43.5	14	350	27.0	S	% N_2 = 0.003
5-11	77.3	63.5	19.8	D-	167	0.111	0.870	0.34	5			d	39.0	15	360	26.5	S	
5-28	76.5	63.6	19.5	D	167	0.093	0.860	0.40	1			d	41.0	17	230	23.5	R	Poor Metal Transfer
5-27	64.1	48.9	35.0	C	126	0.095	0.740	0.31	1			d	130.0	6	230	25.0	R	

(1) a = Coated for stabilization
b = Cleaned but not coated
c = Phosphate coated
d = As-received from mill

Electrode Dia. - 1/16 inch
Average electrode analysis -

%C	%Mn	%Si	S/P
0.13	1.10	0.47	0.022

Interpass Temperature = 200°F unless otherwise noted.

Examination of the techniques used to make welds failing to meet the requirements provide a clue as to those techniques that should be avoided in order to obtain optimum results. The weld metal that did not reach the required minimum yield strength for E6012 electrodes was deposited at a very high energy input per inch of weld (130,000 joules/inch/pass/) using full-weave manipulation. In six other welds, having less than 22% elongation, two were made using straight-polarity direct current with oxygen additions of 3 and 5% to the shielding gas. Three of these low-elongation welds were made using relatively poor metal transfer caused by (1) a very short arc (in argon plus 1% oxygen), (2) a very low current arc, 230 amp (in argon plus 1% oxygen) and (3) helium shielding. The reason for the failure of the seventh weld to meet the requirements is unknown, but it was noted that this weld was made with the maximum number of passes—28. The seven deposits having 22 to 25% elongation were made as follows: (1) 3% oxygen in the shielding gas and reverse polarity, (2) 5% oxygen in the shielding gas and reverse polarity, (3) alternating current with 150 v on open circuit (relatively poor metal transfer), (4) phosphate coated wire with 100° F interpass temperature, (5) and (6) argon plus 1% oxygen in reverse polarity and (7) stabilized wire operated in straight polarity. Another deposit with 25.5% elongation was made with phosphate-coated wire and 100° F interpass temperature. Summarizing, it appears that high oxygen content in the gas, poor metal transfer and low interpass temperature will tend to reduce elongation.

The elongation is related to the soundness of the weld metal. Five of the seven joints failing to meet the required minimum elongation for E6015 electrodes had porosity ratings of D. The total number of welds having this rating was eight. Additional evidence of the influence of porosity of elongation is shown in Table 3 and Fig. 2.

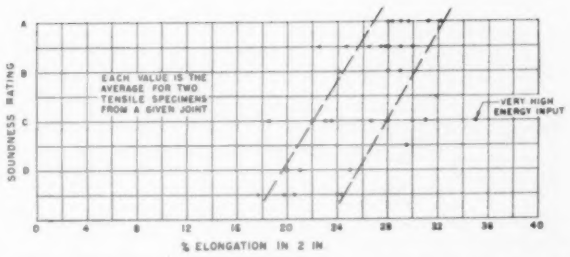


Fig. 2 Influence of porosity on weld metal elongation

If porosity greater than that shown by "D" occurs with killed-steel plate and wire, it is reasonably certain that there is insufficient gas shielding of the weld pool, causing aspiration of air, or there is water in the gas passages or on the wire. Occasionally such an effect is noticed at the start of a weld. This can be overcome by utilizing a 5-sec gas purge prior to striking the arc. If this type of porosity is present throughout the weld, a thorough check should be made of the shielding gas passages in the gun to remove all possible obstructions (for example accumulation of weld metal spatter in the nozzle and inner barrel of the gun).

Table 3—Minimum Elongation Obtained for Various Degrees of Weld Metal Soundness

Soundness rating of joint	*No. of tensile specimens tested*	*Minimum elongation in 2 in., %*
A	20	26
B	16	22
C	16	18.5
D	17	17

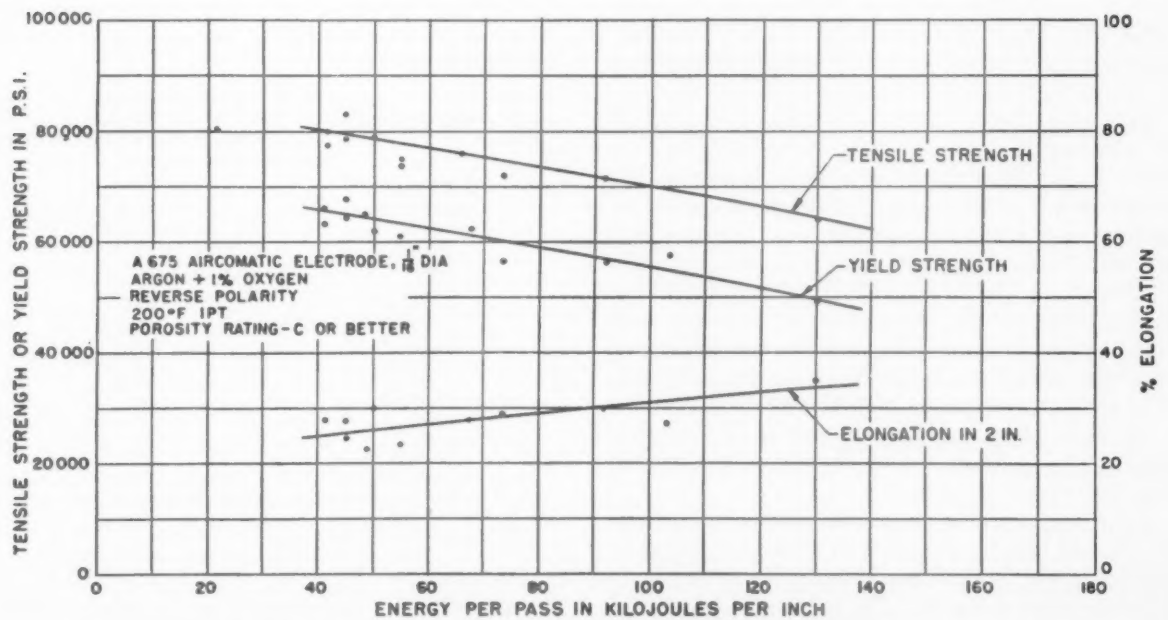


Fig. 3 Influence of energy input on weld metal mechanical properties

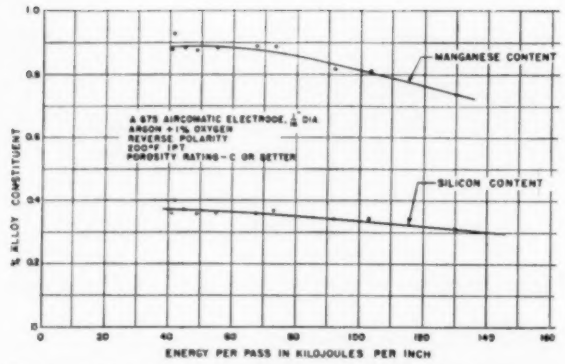


Fig. 4 Influence of energy input on weld metal composition

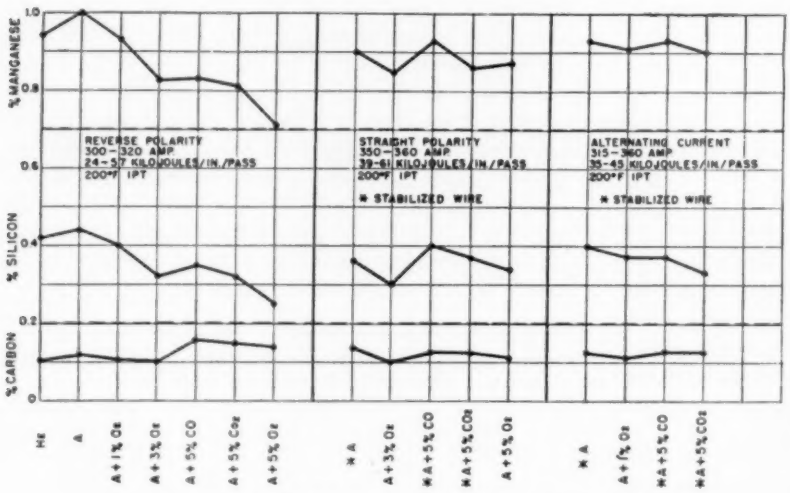


Fig. 5 Effect of shielding gas on weld metal composition

Porosity in weld deposits, with all other factors constant, is dependent upon arc length. There is an increased porosity present with a shorter welding arc. While the strength of these deposits remains constant, there is a slight increase in ductility with a long welding arc.

There is no direct correlation between cleanliness of the wire surface and the porosity of the weld metal because of the influence of many other factors on the soundness of a weld deposit. However, when the results obtained with electrodes cleaned by various methods are compared to those electrodes retaining some portion of the drawing lubricant, it is evident that clean electrodes favor the production of sound weld metal. Sixty per cent of the deposits from 21 cleaned electrodes had a rating of B or better, whereas only 30% of 13 uncleaned electrodes produced weld metal with a B or better rating. Lubricant used in wet drawing when a copper finish is provided causes less trouble than dry soaps or greases.

The energy input influences the mechanical properties of weld metal. The effect is illustrated in Fig. 3. Composition of the weld metal also is affected by energy input as shown in Fig. 4. The increased loss of manganese and silicon with energy increase may be caused by (1) the greater opportunity for oxidation in the larger molten puddle or (2) the increased time available for oxidation to occur. An increase also occurs in the amount of refined weld structure. The high energy input was accompanied by use of weaved passes instead of stringer beads. There was no difference in mechanical properties between deposits made with forehand or backhand technique for the same energy input.

The tensile strength of the deposit is affected by the shielding gas because it affects the weld metal composition as shown in Fig. 5. Carbon dioxide and carbon monoxide are beneficial additions to the argon-shield gas in so far as tensile strength is concerned. The strength of some of these deposits were as high as those obtained with pure shield gas. This may be due to the carbon pickup indicated by chemical analysis of the deposit.

Although the electrode was originally intended for E60XX welding, some deposits would undoubtedly have met the requirements of the E70XX and E80XX specifications if they had been stress relieved. The as-welded properties were compared to the stress-relieved requirements of these specifications with the results shown in Table 4.

Because of the lower elongation requirements for E8010 and E8015 electrodes, the pure argon and helium deposits which would not pass the E6010 and E6015 specification would probably have exceeded the minimum values for E8010 and E8015 if they were stress relieved. Six of the 15 deposits having tensile strengths greater than 80,000 psi were made with pure inert gas. There was no pure-gas deposit having a tensile strength less than 80,000 psi.

Table 4—Comparison of Weld Metal Properties of 35 Deposits to Property Requirements of AWS Filler Metal Specifications

Electrode classification no.	*No. of deposits meeting requirements*
E6010	28
E6012	34
E6015	28
E6020	21
E7010*	25, 25†
E7013*	30
E7015*	25
E7020*	18, 22†
E8010*	10
E8013*	12
E8015*	10
E8020	9

* As-welded properties are compared to stress-relieved properties of specification.
† Compared to 1942 as-welded requirements.

Impact Tests. Nine impact specimens were tested from each weld. Three were tested at room temperature, three at 0° F, and three at −40° F. The aver-

ages of three specimens for each temperature are shown in Table 5 arranged in accordance with decreasing values at room temperature. Comparison of the welding technique to the room-temperature impact strength discloses one outstanding fact—the highest

Table 5—Impact Strength of Weld Metal

Specimen	*Charpy Vee-Notch Impact-Strength in Ft-Lb*		
no.	*RT*	*0° F*	*−40° F*
5-36	...	160	105
4-141	165	119	78
4-20	152	79	46
4-21	149	111	39
4-18	148	92	62
4-19	146	88	64
4-142	143	112	73
4-32	140	118	85
4-31	140	100	82
5-6	135	112	55
4-21A	134	106	66
4-23	133	105	51
5-29	126	59	71
4-24	125	81	55
5-10	123	111	52
5-27	122	93	49
5-15	122	65	43
4-151	119	88	60
5-25	116	66	66
4-11	112	62	26
5-16	111	95	72
5-28	110	67	37
5-13	109	82	61
5-9	109	35	27
4-17	108	58	32
5-18	107	78	37
5-17	107	77	45
5-30	104	57	43
4-12	97	54	41
5-12	97	60	46
5-26	95	52	14
5-11	83	65	17
4-152	77	41	11
5-14	73	43	38

NOTE: Each value is the average of three specimens.

strengths were obtained with stabilized electrodes. In the group of seven stabilized electrodes, three were deposited with alternating current; three with straight-polarity direct current, and one with reverse-polarity direct current. It is interesting to note that two of the three lowest values were obtained with straight-polarity direct current using shielding gas additions of 3 and 5% oxygen. The third low value was obtained using an 85% CO–15% CO_2 mixture. It is probable therefore that the low values result from a high oxygen content in the weld metal. Low values also result when high energy inputs are used with full-weave manipulation.

Comparison of the various microstructures gives no indication of the relation of structure to impact properties. There was little variation in the size of the grains occurring in areas of the weld refined by subsequent passes. There was, however, a noticeable difference in the amount of nonmetallic inclusions among the various welds. The difference was traced to the welding technique used. Forehand welding resulted in an even distribution of fine inclusions while backhand welding produced larger, more easily discernible inclusions.

Increasing interpass temperature on one joint from 200 to 400° F had a very strong effect on the impact strength at 0 and −40° F, causing increases of 100 and 30 ft-lb, respectively. An increase in elongation also resulted while the tensile and yield strengths decreased.

The welding technique that has been used most frequently and has proved satisfactory for many applications is 99% argon–1% oxygen-shielding gas with reverse-polarity direct current. The variation of impact strength with testing temperature for this technique is shown in Fig. 6.

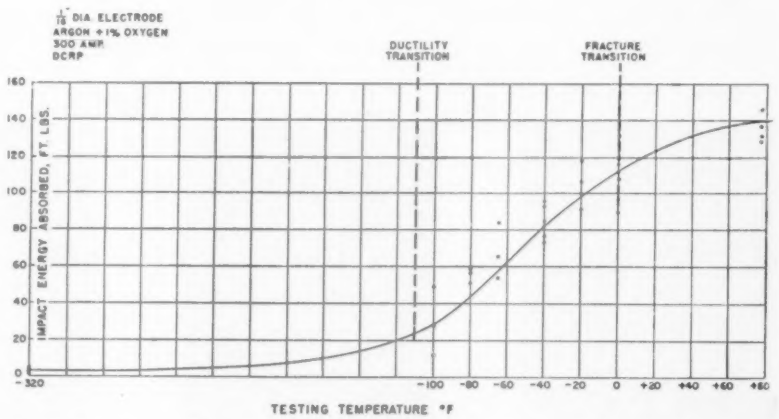
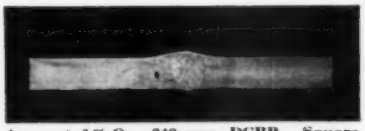


Fig. 6 Vee-notch Charpy impact strength of weld metal deposited by A675 Aircomatic electrode

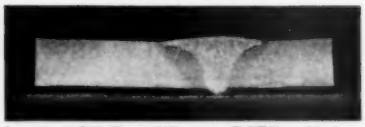
Joint Properties

For manual butt welding, in either flat or horizontal position, with ground or scaled plate, the best results are obtained by using 320 amp DCRP with either argon + 1% oxygen or argon + 5% CO_2. Satisfactory joints could be made with DCSP and an argon-oxygen mixture only if the work was cleaned by grinding the surface. Single-pass butt welds in the flat were made in $^1/_4$-in. plate using a square butt joint with $^1/_8$-in. spacing when DCRP and A + 1% O_2 were employed. The root was backed either with a copper bar or a steel strap. Two passes were necessary with the $^3/_8$-in. plate using a 60-deg single-vee groove and $^1/_{16}$- to $^1/_8$-in. root opening. This opening was advantageous to insure good root penetration. Here again either copper or steel can be employed for the backing. A 60-deg double-vee bevel joint with $^1/_{16}$- to $^1/_8$-in. root opening was employed with the $^1/_2$-in. plate. In this case one pass on each side was usually sufficient to produce a satisfactory joint. Figure 7 shows sections of typical joints made with these conditions. The root passes on all but double-vee joints were made with copper backing.

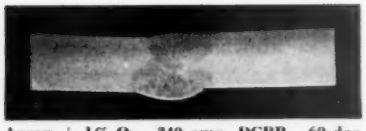
"Oxide-free" surfaces



Argon + 1% O_2. 340 amp, DCRP. Square butt; 1 pass. Root gap, 1/16-in. Speed, 9.0 imp total. Plate thickness, 1/4 in.

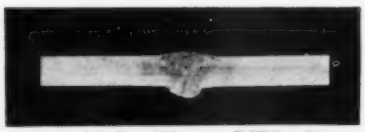


Argon + 1% O_2. 340 amp, DCRP. 60-deg single-vee; 2 passes. Root gap, 1/16-in. Speed, 5.5 ipm total. Plate thickness, 3/8 in.

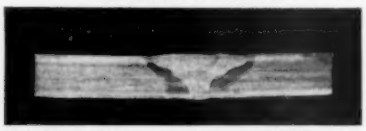


Argon + 1% O_2. 340 amp, DCRP. 60-deg double-vee; 2 passes. Root gap, 1/16-in. Speed, 5.0 ipm total. Plate thickness, 1/2 in.

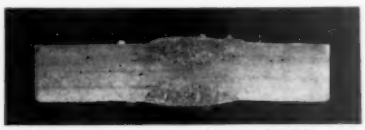
"As-flame-cut" surfaces



Argon + 2% O_2. 325 amp, DCRP. Square butt; 1 pass. Root gap, 1/16-in. Speed, 7.0 ipm total. Plate thickness, 1/4 in.



70 helium:30 argon. 320 amp, DCRP, 60-deg single-vee; 3 passes. Root gap, 1/16-in. Speed, 7.0 ipm total. Plate thickness, 3/8 in.



70 helium:30 argon. 340 amp, DCRP. 60-deg double-vee; 2 passes. Root gap, 1/16-in. Speed, 5.2 ipm total. Plate thickness, 1/2 in.

Fig. 7 Unrestrained flat butt welds on hot-rolled semikilled plate using 1/16-in. A675 Aircomatic wire

For butt welds made in the horizontal position the optimum joint design with 1/4-in. plate is again square butt with 1/8-in. root opening. This opening can be reduced if the plate edges are ground to a slight bevel. For 3/8- and 1/2-in. plate either single- or double-vee bevel joints with 60-deg included angle can be employed, although it was felt the double bevel was easier to fill, and resulted in a better joint.

Welding in the horizontal position was greatly facilitated by reducing the electrode size from 1/16 to 0.045 in. This permitted the use of lower welding current which made for a smaller molten pool to cope with. The argon + 5% CO_2 mixture was much superior in producing horizontal butt welds in the as-cut plate, although it was no better than argon + 1% oxygen on ground plate. Figure 8 pictures typical horizontal joints made under the optimum conditions.

One condition where helium mixtures were particularly helpful was in the welding of as-cut butt joints in the flat position on 3/8- and 1/2-in. plate. (See Fig. 7.) There the 70% helium – 30% argon mixture produced satisfactory results.

For fillet welds in either flat or horizontal position, in all size plate, and in either plate condition the DCSP, argon + 3% O_2 or DCRP argon + 1% oxygen conditions produce welds of good appearance and properties. The increased deposition rate of the DCSP condition provides it with an economic advantage of course. The fillet welds in Fig. 9 were made with optimum welding conditions for each particular plate size and surface condition.

The welds shown were made under those conditions which produced welds of best quality at the fastest speed. Fillets made with alternating current (75-v open circuit) using a stabilized electrode operating in argon exhibited no undercut at high current and high travel speed. On mill scale surfaces d-c straight polarity using argon and 2% oxygen produced satisfactory sound welds at highest travel speed.

The addition of 5% CO_2 to argon seemed to produce excessive undercutting in the vertical leg of the fillets to make it useful for the horizontal welds. It produces excellent results in the flat position, however.

For manual welding the use of the CO-CO_2 mixture produces excessive spatter and has poor operator appeal in flat position welding. This can be said of pure helium although to a lesser degree. These shielding gases have foundparticularapplication in automatic welding and will produce excellent results on high-speed welding of steel 1/8 in. and less in thickness.

"As-flame-cut" surfaces

Argon + 5% CO_2. 180 amp, DCRP, Square butt. Root gap, 1/16-in. 1 pass each side. Speed: 3.8 ipm total. Plate thickness, 1/4 in.

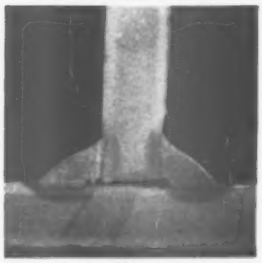
Argon + 5% CO_2. 180 amp, DCRP, 60-deg single vee. Root gap, 1/16-in. 3 passes. 2.8 ipm total. Plate thickness, 3/8 in.

Argon + 5 % CO_2. 180 amp, DCRP, 60-deg double-bevel. Root 1/16-in. 4 passes. 2.0 ipm total gap. Plate thickness, 1/2 in.

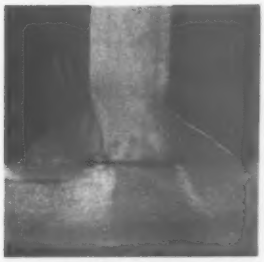
Fig. 8 Unrestrained horizontal butt welds on hot-rolled semikilled plate using 3/64-in. A675 Aircomatic wire

"Oxide-free" surfaces

Argon + 1% O_2. 300 amp, DCRP. Speed: 12 ipm. Plate thickness, 1/4 in.



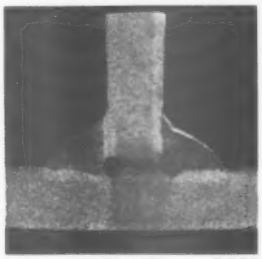
Argon-stabilized electrode. 390 amp, A.C. 15 ipm. Plate thickness 3/8 in.



Argon-stabilized electrode. 390 amp, A.C. 12 ipm. Plate thickness, 1/2 in.

"As-flame cut" surfaces

Argon + 2% O_2. 360 amp, DCSP. Speed: 16.5 ipm. Plate thickness 1/4 in.



Argon + 2% O_2. 370 amp, DCSP. 16.0 ipm. Plate thickness, 3/8 in.

Argon + 2% O_2. 360 amp, DCSP. 12.0 ipm. Plate thickness, 1/2 in.

Fig. 9 Fillet welds made with 1/16-in. A675 Aircomatic wire on hot-rolled semikilled plate (position as pictured)

Tests Conducted in Accordance with Military Specification MIL-E-986A

Using A + 1% O_2 and DCRP this electrode will produce deposits that meet the requirements of MIL-E-986A specification for MIL-180 covered metal-arc electrodes as shown in Table 6. Figure 10 shows the structure of the groove weld deposit and is typical of the weld structure obtained with this electrode material.

Direct Explosion Tests

Table 7 compares the direct explosion results obtained with several welding processes to the results obtained with the prime plate, a ship hull grade of steel. From these data it is apparent that the multipass techniques of the inert-gas process are superior to large single-pass deposits as characterized by submerged-arc deposits. This superiority is one of increased impact or shock resistance. This is undoubtedly due to the lack of a continuous columnar grain structure through the weld. This type structure with the long columnar grain boundaries transverse to the weld is bound to exhibit poor impact at this highly notched point. There is some question as to the reliability of these results since the plate welded by the inert-gas method fared better than the prime plate at 32° F. This may be accounted for by the fact that later work disclosed this plate to have poor impact properties. It is surmised that the weld, being of a notch tough material, complemented the deficiencies of the poor plate to produce a composite with improved energy absorption.

Table 6—Qualification Tests of Airco A675 Electrode Under Military Specification for Low-Hydrogen Electrodes for Medium Steel (MIL-E-986A (Ships) Type MIL-180-15 Class 2)

Groove patch plate[a]

Sample[b]	*X-ray*	*Charpy keyhole impact strength, ft-lb* 0° F	−20° F	*Brinell hardness*
A-(1)	Acceptable[c]	38, 39, 39, 44	38, 38, 39, 43	181
B-(1)	Acceptable[c]	37, 39, 41, 44	35, 37, 37, 44	183
A-(2)	Acceptable[c]	33, 34, 38, 38	32, 35, 35, 36	178
A-(2)	Acceptable[c]	38, 39, 41, 41	38, 38, 38, 40	182

Groove-butt joint[d]

Type of bend	*Bend, deg*	*Cracks*
Root	180	None
Face	180	None

Weld metal tensile properties[e]

Tensile strength, psi	84,000
Yield strength, psi	70,000
Elongation in 2 in., %	24.5

Fillet welds[f]

Fillet size, in.	3/8
Undercut	None
Contour	Good

[a] See Fig. 4, MIL-E-986A; one inch HT Plate. Flat position. 99% argon + 1% oxygen; 300 amp DCRP. Preheat and interpass temperature 0° F.

[b] A = 6 in. patch plate. B = 4 in. patch plate. (1) = Quadrant procedure. (2) = Continuous layers.

[c] Group 1 (Navships No. 250-692-2). X-ray Standards for Production and Repair Welds.

[d] General Specification for Inspection of Materials, Appendix VII, Sect. E-1, Navy Dept.

[e] See Fig. 5, MIL-E-986A; one inch HT plate. Flat position. 99% argon + 1% oxygen; 300 amp DCRP. Preheat and interpass 100° F max.

[f] See Fig. 2, MIL-E-986A; one-half inch HT plate. Horizontal position. 99% argon + 1% oxygen; 300 amps, DCRP. Preheat 100° F max.

Table 7—Test Results of Direct Explosion Tests on Welded Ship Hull Steel

Spec. no.	*Welding procedure*	*Charge, gm*	*Extent of Fracture*
	Test temperature = 10° F		
1	None (prime plate)	280	4 pcs.
2		360	6 pcs.
3		440	8 pcs.
4		520	8 pcs.
5		606	10 pcs.
1	Submerged arc, two-pass, 70° F pre-	40	4 in., back only
2	heat and ipt	60	4 in., back only
3		80	12 in., back only
4		120	3 pcs.
5		200	3 pcs.
1	Grade 180 electrode, 7-pass, 70° F	140	32 in.
2	preheat and ipt	140	3 pcs.
3		140	4 pcs.
4		140	2 pcs.
5		140	3 pcs.
1	Inert-gas metal-arc, A675 electrode,	160	None
2	70° F preheat and ipt	200	None
3		200	None
4		200	5 pcs.
5		240	3 pcs.
	Test temperature = 32° F		
1	None (prime plate)	140	None
2		140	26-in. crack
3		160	34-in. crack
4		160	2 pcs.
5		200	34-in. crack
1	Submerged arc, two-pass, 70° F pre-	80	None
2	heat and ipt	100	12-in. front, 20-in. back
3		120	28-in. front, 37-in. back
4		140	27-in. front, 32-in. back
8		160	25-in. front, 26-in. back
1	Grade 180 electrode, 7 pass, 70° F	140	22-in. front, 25-in. back
2	preheat and ipt	160	None
3		160	2 pcs.
4		200	37-in. front, 39-in. back
5		280	4 pcs.
1	Inert-gas metal-arc, A675 electrode,	200	None
2	70° F preheat and ipt	280	None
3		280	None
4		320	3 pcs.
5		360	4 pcs.

Emissive Agents

Inert-gas metal-arc welding can be performed if a transformer having an open-circuit voltage of 150 v is used provided that sufficient oxygen is added to the argon shield. With this technique, the arc is relatively unstable. Specimen 4-31, Table 2, made in this manner, exhibited considerable porosity because of this arc instability.

2 × Mag

Fig. 10 Weld macrostructure obtained using argon plus 1% oxygen and reverse polarity current at 300 amp (deep etched with ferric chloride)

The a-c arc stability can be greatly improved by applying one of a number of emissive agents to the electrode. Use of an emissive agent permits the performance of a-c welding with a transformer having an open-circuit voltage of 75 v. It is probable that lower voltages also can be used. A quiet, steady arc is obtained with good metal-transfer characteristics.

When using pure argon, a-c power, and an electrode coated with an emissive agent, the stringer beads are sound, but they have a high, rounded cross section. This shape makes it difficult to obtain good interbead fusion and accounts for the fusion line porosity of Specimen 4-32. The tendency to form high, rounded beads also is a characteristic of argon with reverse-polarity direct current, but it is slightly accentuated with alternating current because less heat is produced in the work.

Additions of 5% CO or 5% CO_2 modify the arc action of the a-c arc with the activated electrode so that the separate beads were more easily fused together to produce a deposit having no porosity and with very good physical properties. The CO or CO_2 additions to the shielding gas were somewhat better than oxygen additions under the same operating conditions.

In addition to this arc stabilizing effect, the emissive

agents also modify the straight-polarity direct current arc so that a steady uniform metal transfer is obtained in argon without the necessity of oxygen additions. The improvement in transfer is accompanied by a reduction of electrode melting rate. The amount of reduction depends upon the quantity of emissive agent used, but the melting rate is higher than that for reverse polarity. The heat evolved at the work is low, and therefore, this technique is particularly useful where it is desirable to have the minimum base metal dilution. This method also should prove useful for welding sheet steel and for increasing the amount of current (and consequently electrode melt rate) that can be applied to a given thickness of material.

The impact strengths of the deposits made with activated electrodes and straight-polarity direct current were good and the tensile properties met the E70XX requirements. The addition of CO or CO_2 to the shield produced lower strength and impact values and more porosity than was obtained with pure argon.

Operating Characteristics

Full evaluation of a welding technique cannot be based solely upon properties of the weld metal, but requires consideration of operator appeal. For reverse-polarity welding, addition of 1% oxygen, 5% carbon monoxide or 5% carbon dioxide was preferred by operators to the use of pure argon, helium or oxygen contents greater than 3%. For straight polarity welding, oxygen contents greater than 3% were preferred for bare electrodes while lower oxygen content or small carbon monoxide or carbon dioxide additions were preferred with activated electrodes. For a-c welding activated electrodes were preferred with a small amount of O_2, CO or CO_2 added to the argon. All the above conditions allowed greater latitude in the manipulation of the electrode. The carbon monoxide-carbon dioxide mixture had the least operator appeal since there was considerable spatter and a long CO flame issued from the gun.

SUMMARY

Inert-gas metal-arc welding can be used with a wide range of techniques to deposit a carbon steel electrode, A675, containing 0.13% carbon, 1.10% manganese and 0.47% silicon, so that the weld metal will meet the E60XX mechanical property requirements for covered metal-arc electrodes. Since no hydrogen is present in the shielding gas, this electrode and process can be used in lieu of E6015 covered electrodes. Impact strength at 0° F is well above that required for MIL-180 electrodes as described in Military Specification MIL-E-986A. With the best available techniques, the weld metal will meet the mechanical property requirements for E80XX covered metal-arc electrodes.

Development of the best mechanical properties in groove welds will be favored by the following modes of operation:

1. Welding with stringer beads instead of full-weave layers.
2. Adjusting current, voltage and travel speed for moderate energy inputs.
3. Using sufficient current for good metal transfer.
4. Maintaining moderate arc lengths (avoid very short arcs that produce spatter).
5. Reducing oxygen contents in the shielding gas to an operable minimum.
6. Remove drawing lubricants from the electrode that prevent a uniform electrode feed.
7. Operate with alternating current using an activated electrode or with reverse-polarity direct current.

High interpass temperatures will improve ductility as measured by a 0.505-in. tensile specimen and also will increase impact strength. If the temperature is too high, however, the yield strength will be lowered.

For horizontal butt welding several additional guides for obtaining the best results are as follows:

1. Use reverse polarity in preference to straight polarity.
2. Grind the surfaces if straight polarity is to be used.
3. Weld with 0.045 in. diam electrode.

Alternating current was not investigated for these butt welds, but it is expected that it will prove as suitable as reverse-polarity direct current.

Single-pass fillet welding was best performed using clean electrodes with straight polarity and 3% oxygen in the shielding gas or reverse polarity with 1% oxygen. Higher deposition rates, however, are obtainable with straight polarity. Fillet welds of superior shape were made using a-c power and activated electrodes with argon.

Forehand welding produces deposits that are different in appearance from those made by backhand welding. The former produces thinner layers with less surface oxidation, and therefore, is more suitable for capping passes in multipass welds. The forehand technique also provides slightly greater penetration than does the backhand method.

In conclusion, it can be stated that welding fabricators would do well to consider inert-gas consumable electrode welding for carbon steel in view of the good joint and weld metal properties obtainable with this process.

PRACTICAL WELDER AND DESIGNER

Salvaging of a Water Stand Tank Originally Erected in 1924

This tank was transported from Brunswick, Md., to Rockville, Md., a distance of approximately fifty miles by the B & M Welding & Iron Works of Gaithersburg, Maryland

SUGGESTED cautionary measures for anyone contemplating this type of a job follow:

(*a*) A thorough inspection of the inside of the tank to be sure that it is salvagable due to rust conditions.
(*b*) A metallurgical analysis of the steel to be sure that it can be welded.
(*c*) Road permits and road clearances have to be thoroughly checked.

Specifications:

Height of tank	60 ft 0 in.
Diameter	17 ft 4 in.
Top sheet, thickness	3/16 in.
Bottom sheet, thickness	5/16 in.

To determine the amount of cutting of this tank, it was necessary to make a road survey of low bridges and wires and any other obstructions in cooperation with the telephone company, the state roads, and the local police of the towns which we were passing through. It was determined that we could not haul anything over 18 ft in height, therefore, a 15-ft section on a low-bed trailer held us to 17 ft, 10 in. Road permits and police escorts were necessary and we were only allowed to transport two sections at one time, thus, four 15-ft sections required three circumferential cuts.

We tried to stay away from the horizontal rivet seams in cutting which we were fortunate in obtaining 12 in. from the seams. The burner jagged around the double row of rivets in the vertical seam not trying to obtain a straight line but used a yardstick and laid it off freehand and started cutting the first section 15 ft from the bottom. We had made clamps to be welded to the tank for realigning the tank together. These consisted of two pieces of one-half flat stock 3 in. wide and 5 in. long with one piece of flat stock 11 in. long. These pieces were tacked together in the manner of 1/2 in. by 5 in. to be above the cut and one below the cut

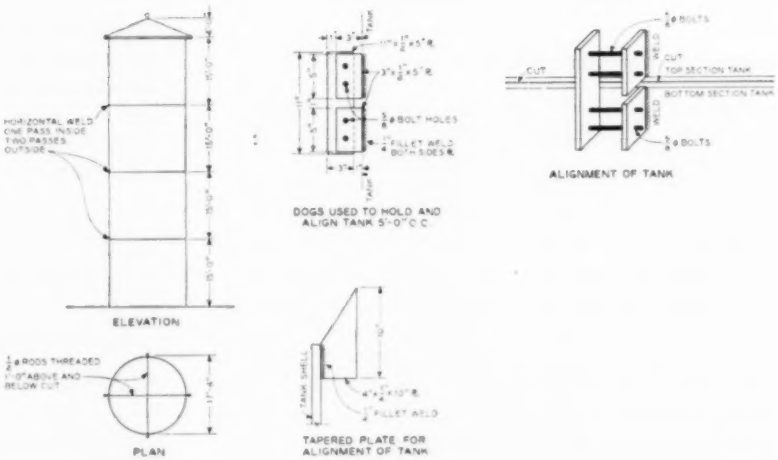


Figure 1

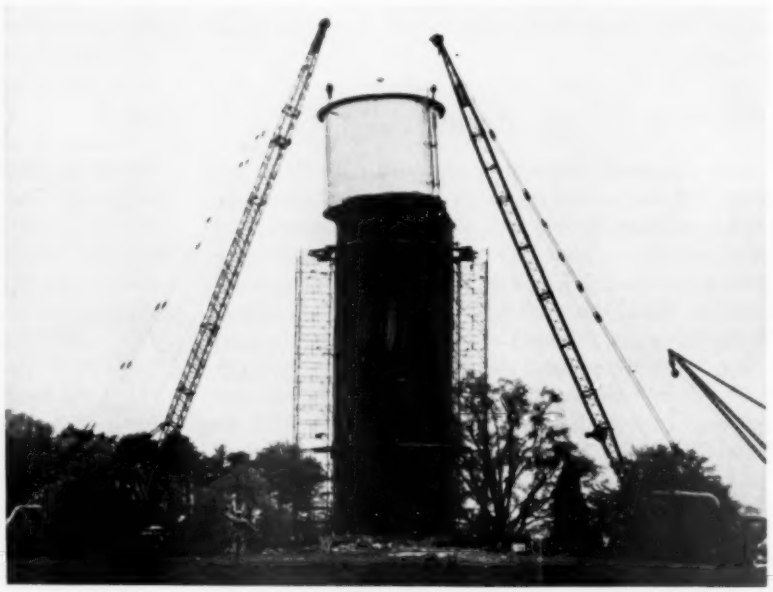


Figure 2

leaving a gap of 1 in. between the ends of the two pieces. The 11-in. piece was held $^3/_4$ in. from the edge of the other two and tack welded. They were then drilled for $^5/_8$-in. bolts, two holes in each 5-in. bracket through the 11-in. piece. The burner would burn a line of 6 in. and then the welder would weld both 5-in. dogs above and below the cuts with a full fillet weld on each side.

The tacks and bolts were left intact until the crane was ready to lift the section. Spacing of these dogs were approximately 5 ft.

For lifting the tank, two angle irons 1-ft long were welded vertically approximately 1 ft 6 in. apart and about 1 ft below the cut at the same height above and below the cut and two $^1/_2$-in. hog rods were run through the diameter of the tank. Holes were burnt with the oxy-acetylene torch and washers and lock nuts were used on the outside only to hold the tank from becoming egg-shaped. A 12-in. eye beam spreader was used on the open end of the lower sections.

Two cranes were used to remove the top section and the lid of the tank was then removed and loaded on trailers for transportation. After the section was set on the trailer, four angle irons were welded across the top diameter of the tank coped and bent down to the top of the gooseneck as their purpose was to throw wires over the top of the tank.

The four sections and the lid were blocked up in the yard of the Lofstrand Co., Rockville, Md., and during the winter they had placed tarpaulins over the top opening and repaired the pits in the sections by electric welding. In two or three places these pits were from $^1/_2$ to 2 in. in width and 8 to 10 in. in height while the major part of them was the size of a quarter. During the winter the ground did not freeze sufficiently for us to gain access to the base of the tank which was on a hill in a wheat field.

With dry enough weather we set the first section with 1 in. of concrete grout to protect the rivet heads on the bottom of the tank. After the grout was thoroughly dried and the anchors cinched, we set the next two sections, welding both of these sections—one pass on the inside first and then two passes on the outside using E6010 $^5/_{32}$-in. electrodes. Two cranes were again required to set the top section and the lid which was painted and the company's sign painted prior to the erection.

On completion of the top weld the tank was pumped full of water and inspected by the Lofstrand Co. Not finding any leaks the job was accepted.

Our contract in moving this tank had a specific clause that we would not erect this tank if the temperature dropped below 50° F for cautionary measures in welding through rivet seams and adjacent to them.

A Steam-Tight Pocket . . . Heliarc Welded

HELIARC welding is being used by one of the country's leading producers of stainless steel kettles. The Groen Manufacturing Co., Chicago, is fabricating steam-jacketed gas kettles, ranging in capacity from 10 gal. upward, for a variety of commercial and industrial uses. The kettles are designed to utilize live steam circulated through an inner shell to provide an even and quick distribution of heat.

The Heliarc process is used to weld a ring canopy to the top of the inner shell for the kettle. This canopy is designed to fit over the edge of the kettle jacket, to support the pot, and to form a steam-tight pocket between the inner and outer shells. During welding the pot is mounted horizontally on a rotating jig controlled by a foot pedal at an average welding speed of 8 ipm.

One of the final fabricating touches in production is the spot welding of a stainless steel name and specifications plate to the side of each kettle. A Heliarc HW-8 torch is used for this job, and the eight spot welds required on this 22-gage plate are completed in an average time of 30 sec. Upon completion no grinding is necessary; the finished kettle unit needs only a high polish.

Fig. 1 As this huge kettle revolves on a rotating jig, a ring canopy is Heliarc welded to the top of the inner shell

Fig. 2 After Heliarc welding is finished no grinding is necessary; the kettle unit needs only a high polish

Fig. 3 A 22-gage stainless steel name and specifications plate is fabricated to the side of each kettle. Eight spot welds required in this operation

"2-in-1" Welding Fixture Speeds Diesel Piston and Valve Reclamation

HALF the trick of building up ring grooves on a worn-out aluminum Diesel piston is a fixture which holds and rotates the piston at desired speeds during sigma welding. Engineers on the Minnesota Transfer Railway have designed a highly efficient piston-turning device, but they did not quit there. Their unit not only rotates the piston, but the other end will also hold and turn Diesel valves for hard-facing operations, as Fig. 1 shows. Welding is done by a SWM-2 portable sigma welder with hand torch and solenium rectifier.

This compact fixture consists of a cabinetlike stand made of $^1/_4$-in. welded sheet metal, upon which is mounted the turning mechanism. Two $^1/_2$-in. metal plates which support the turning shaft are welded 2 $^1/_2$-ft apart in an upright position on top of the stand. Tops of these plates are cut in a half-circle to accommodate a light metal hood which fits over the work and retains the preheat.

The piston is held in position lathe-fashion. It is threaded on the top end to fit and tighten onto a small spindle. A center head on the power shaft fits into the bottom end of the piston for turning. Welding is performed down-hand through a 12- x 8-in. opening in the

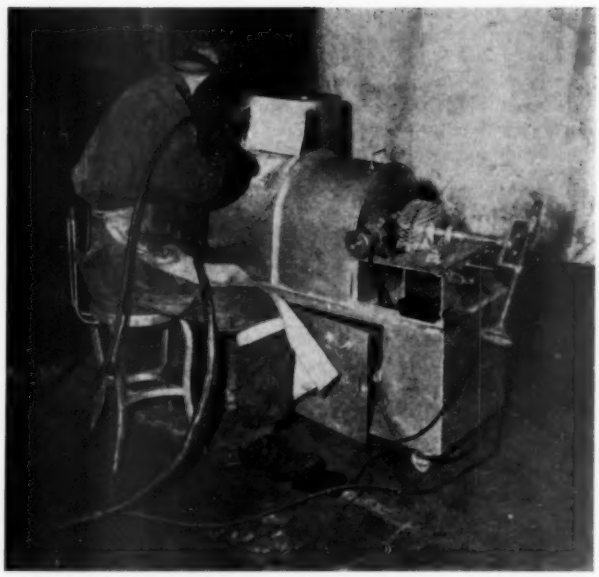


Fig. 2 Here a welding operator is putting the piston-turning end to use by building up an aluminum piston with a sigma welding unit. Work is done down-hand through a door in the hood. Note that his right foot can regulate the speed of the rotating piston

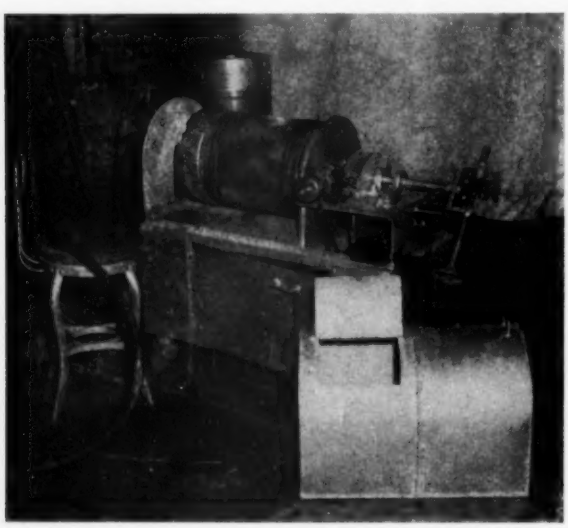


Fig. 1 Over-all view of a combination piston-valve turning fixture in use at the Minnesota Transfer Railway Shops. Hood in the foreground fits over the piston-turning section to keep in preheat. Foot rheostat for controlling motor speed is also visible

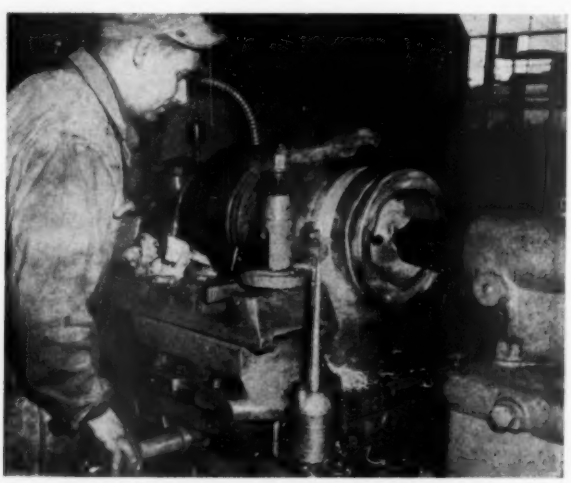


Fig. 3 Machining operations on the built-up piston are done on this lathe which has been adapted to turn the piston down to its original dimensions. New ring grooves are machined-in after this step

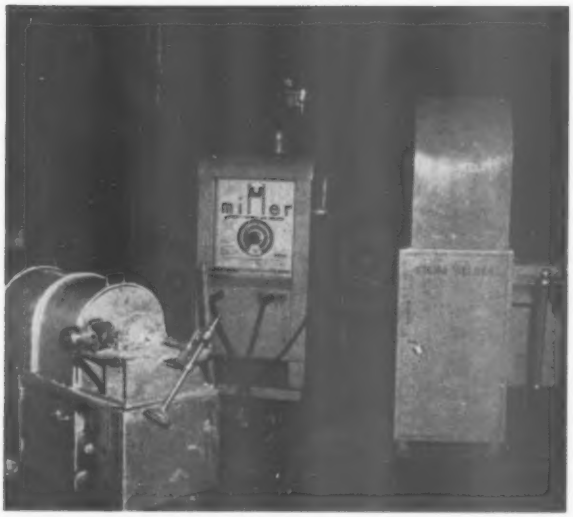


Fig. 4 Compactness of the piston-valve turning unit is evident in this photo. The turning fixture is at the left, generator and argon cylinder in the center, while the unit on the right houses the sigma welding machine under its removable hood. All units are mounted on wheels for easy portability

hood. A metal door closes over the opening between operations to prevent loss of preheat.

Before ring grooves on the piston are built up, the grooves are machined out $^1/_{16}$ in. on each side and on the bottom. This is followed by preheating to 300–400° F. with an oxy-acetylene blowpipe. Rod used is "Oxweld" No. 23 $^1/_{16}$ in. A single-ring groove on a 12 $^1/_2$-in. piston can be built up in 30 min with d-c reverse polarity at 240 amp. Argon flow is 25–30 cfh. After welding, the piston is machined to original size, as shown in Fig. 3, and new ring grooves are made.

An extension of the piston-turning shaft permits its use in the rotation of a valve for hard-facing work. The end of the shaft is set in a small fixture which holds a valve at a 45-deg angle for down-hand welding. Bevel gears on the end of the shaft and on the fixture transmit the turning motion from the shaft to the valve.

Valves are hard-faced with $^3/_{16}$-in. diam rod using an oxy-acetylene blowpipe. A $^1/_{16}$- to $^1/_8$-in. deposit can be applied to a 4-in. valve in 30 min with this setup. Grinding completes the operation.

Power for the unit is supplied by a $^1/_{25}$-hp, 5-v, 8000-rpm, a-c motor equipped with a gear reduction unit and governor assembly. Variable revolving speeds from 19 to 197 ipm are made possible by the use of a foot-operated rheostat visible in Fig. 2.

Strong Aluminum Alloy Gets Pressure Vessel Code Approval

MANUFACTURERS and users of unfired pressure vessels are offered a valuable new construction material with the recent approval of aluminum alloy GR40A by the Boiler Code Committee of The American Society of Mechanical Engineers. Alloy GR40A (designation of American Society for Testing Materials) is commercially designated by Aluminum Company of America as A54S.

Approval of this alloy became effective with the publishing of ASME Case 1174. This case permits the construction of unfired pressure vessels of A54S alloy in accordance with the rules of Section VIII of the 1952 ASME Boiler and Pressure Vessel Code.

Alcoa alloy A54S offers higher mechanical properties than any of the alloys previously approved for welded pressure vessels (3S, 52S, 4S, etc.): For this reason, allowable design stresses are higher. For elevated temperature operation, A54S alloy becomes even more desirable because it maintains its strength better at higher temperatures. This fact is clearly shown in the table below. Design stresses in this table are shown only for the −0 (annealed) temper, since welded designs are based on the properties of the annealed tempers of these alloys.

Although A54S alloy can be welded by all conventional methods, the semiautomatic inert-gas metal-arc process and the inert-gas metal-arc process (tungsten-arc) are preferred. Laboratory tests and vessels in actual use have shown that the tensile strength of butt (groove) welds in A54S material, using A54S filler wire, will exceed the minimum tensile strength of A54S-O by a comfortable margin.

While A54S is more expensive than 3S and 4S alloys on an equal weight basis, it is definitely more economical on the basis of equivalent strength. The weight saved in vessels fabricated from this alloy will normally more than offset the increased cost per pound, and the lighter weight in itself is often a valuable advantage. These economies are expected to result in the use of aluminum for many vessels formerly made of other materials, thereby opening up entire new fields for aluminum.

	Metal Temperature, ° F, Not Exceeding:						
Alloy	*100*	*150*	*200*	*250*	*300*	*350*	*400*
3S-O (M1A)	3350	3150	2900	2700	2400	2100	1800
4S-O (MG11A)	5650	5650	5650	5500	4650	3850	3150
52S-O (GR20A)	6250	6250	6200	6000	5400	4650	3900
A54S-O (GR40A)	7350	7350	7350	7000	6400	5650	4900

Low-Temperature Welding Alloys* Speed and Simplify Structural Model Fabrication†

by Sidney Shore and Edward W. Rothfuss, Jr.

IN 1949 a project was undertaken by the Civil Engineering Department at Princeton University to construct a steel model, 312 in. long, that was to simulate a 312-ft section of the stiffening truss of the Delaware Memorial Suspension Bridge. The prototype, spanning the Delaware River, is the fifth longest suspension bridge in the world, and is located south of Wilmington, Del. The model, primarily was to provide empirical data for the designers of the prototype in order to determine the adequacy of the lateral bracing. The second purpose for the model construction was to study the effect of torsional loading upon the stiffness and stress distribution in the truss of a suspension bridge. The unique features of this model were that it was designed and built as a space framework and that it duplicated the prototype's members, connections and other structural details. Figure 1 shows the Princeton model fabricated (except for lateral bracing) and Fig. 2 shows some of the structural details.

The somewhat "elaborate" Princeton model was justified on the basis that many engineers refuse to accept the results on planar models which duplicate actual structures only with respect to the geometry of articulation of the members. In an effort to prove the validity and the usefulness of "simplified" models, plans were made to build another smaller model of the prototype that would not incorporate the structural details. It was felt that if a simplified model could be fabricated on a smaller scale and results obtained within 10 to 15% of those obtained on the Princeton model, a great savings in time and money could be effected. Due to the ease of fabrication, it was decided to use brass plates and tubing. Consequently, this project was initiated by the senior author at MIT, and was completed by the writers at Princeton University.

The brass model of the Delaware Memorial Suspension Bridge stiffening truss simulated the prototype on a static similitude basis. The use of brass tubing for members and the brass sheets for floor beams and gusset

Sidney Shore is Associate Professor of Civil Engineering, University of Pennsylvania, and **Edward W. Rothfuss, Jr.**, was a Graduate Student, Princeton University.

* Trade mark of Eutectic Welding Alloys Corp., Flushing, N. Y.

† This article was a winning entry in the 1952 Prize Competition of the Eutectic Welding Alloys Corp.

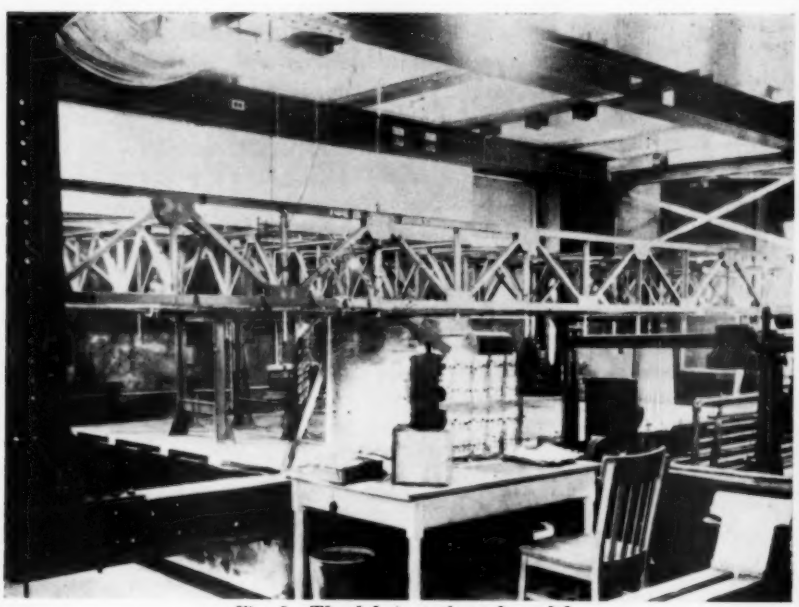


Fig. 1 The fabricated steel model

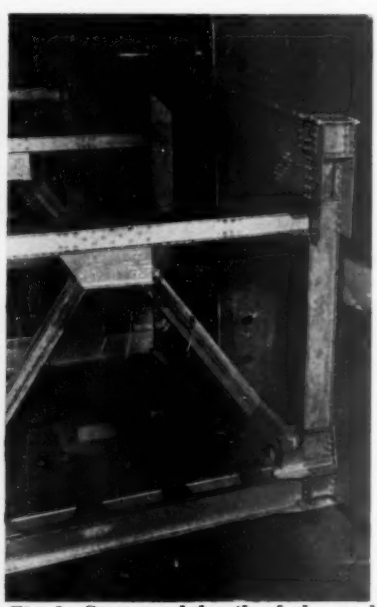


Fig. 2 Structural details of the steel model

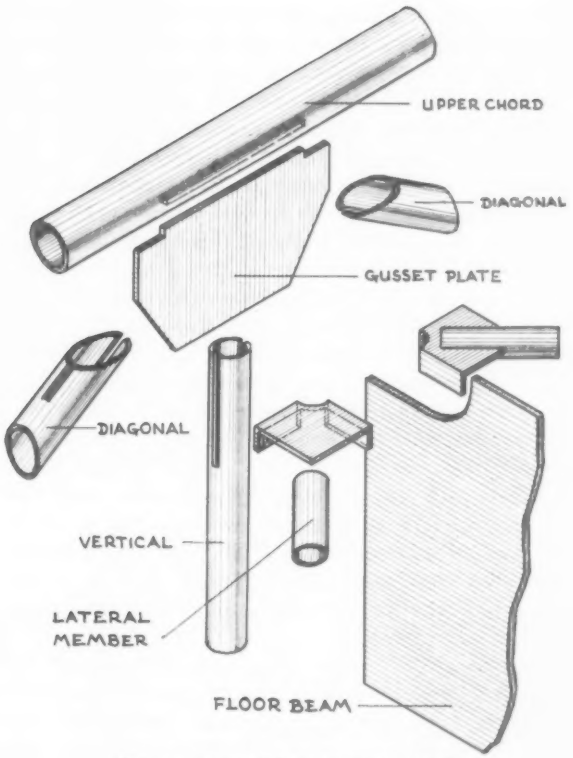


Fig. 3 A typical main truss joint

plates bases the design essentially on the equivalence of the axial unit strains due to axial forces only in the members of the prototype and model. This design simplification is reasonable for all members except the four chords of the main truss, since the axial unit strains due to flexure and torsion amount to an additional 15%. This percentage is based on the test results of the Princeton model of the prototype.

The model has a scale-reduction factor of 54:1 with respect to the prototype. With respect to the Princeton model this factor is 4.5:1. Brass tubing was used for the majority of the members while brass plates were used to simulate the floor beam trusses and gusset plates. The completed model is 69.33 in. long, 13.55 in. wide and 4.44 in. high. The floor beams are 3.35 in. high. The structure has rigid connections at all joints, but in general no attempt is made to duplicate structural connections of the Delaware Bridge. This is obvious in view of the 54:1 scale reduction factor. The following procedure was devised to obtain rigid connections for members framing into a joint. Slots were cut in the main chord members which received notched gusset plates. A special silver brazing-type alloy No. 1801 was employed to braze the parts in place. Next, axial slits were machined at the ends of all members which enabled them to be slipped onto the gusset plates. Refer to Fig. 3.

Tests, using the silver alloy and the corresponding flux, were run on sample joints which simulated the type of connections which were to be used in the model. All combinations of plate thicknesses and tube diameters were used in determining the strength of the special filler metals. The results of all tests showed that the brass parent metal either yielded or ruptured before the failure of the filler metal. Additional tests were run to determine the effects of the high melt temperature of the special silver alloy on the mechanical properties of the brass parent metal. No detrimental effects were noted. It was therefore decided that this special high melting silver alloy would provide the required bond strength in joints where relatively high-tensile and shear stresses would occur.

The procedure followed in the fabrication of each of the two main stiffening trusses consisted of first brazing all the gusset plates to the upper and lower main chord members. To accomplish this, the upper and lower chord members were firmly attached to a fireproof surface and each gusset plate then brazed in position.

With the upper and lower chord members properly spaced and firmly attached to a fixed surface, the web members consisting of verticals and diagonals were inserted into position. Working alternately from the middle outward each web member was brazed so that one side of the now assembled stiffening truss was permanently brazed. It was then turned over and the process repeated for the other side completing the subassembly for the main trusses.

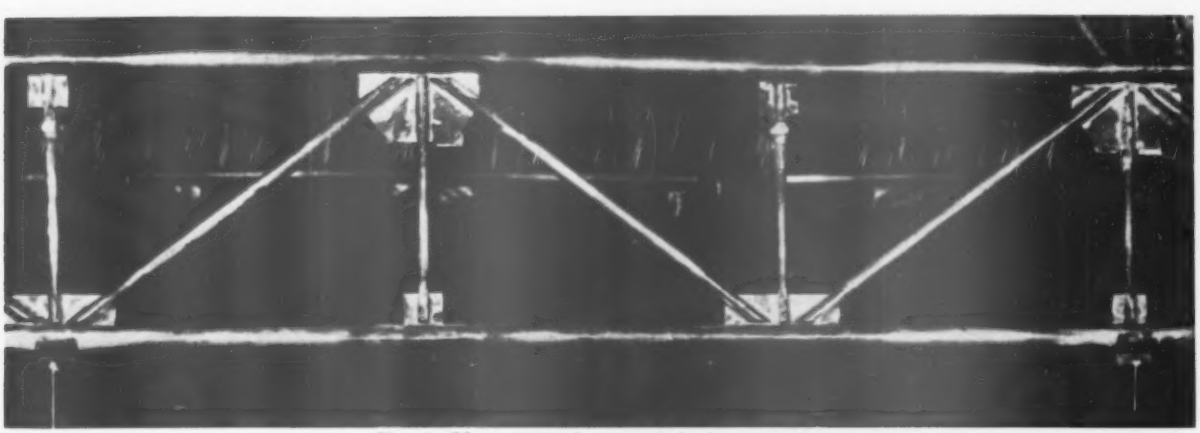


Fig. 4 Main vertical truss of the brass model

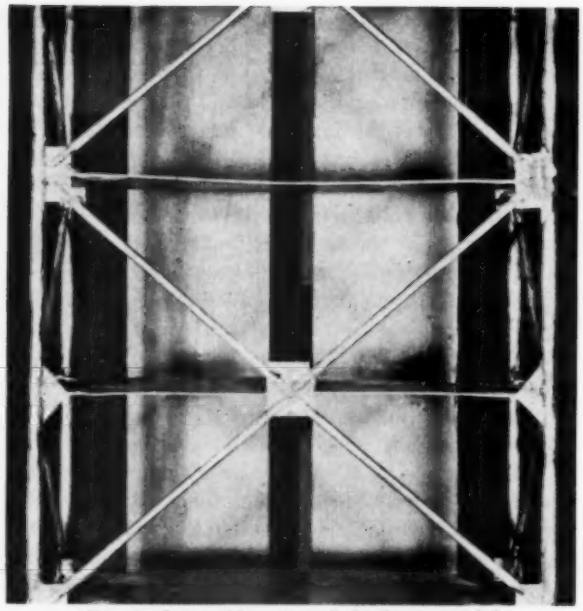


Fig. 5 Lateral bracing of the brass model

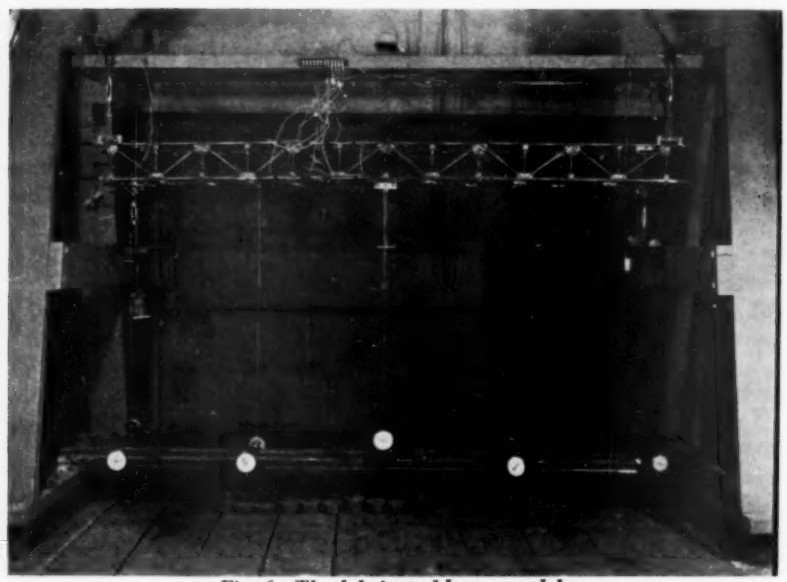


Fig. 6 The fabricated brass model

In order to connect the two main stiffening trusses to the floor beams a jig was utilized. The jig permitted one stiffening truss to be firmly attached to a fireproof surface while one side of the floor beam was brazed to gusset plates previously welded in place on the vertical members of the stiffening truss. The floor beams were supported and clamped so that each one was perpendicular to the truss and at the correct distance from the upper chord member. To attach the second stiffening truss to the floor beams the above process was repeated.

To duplicate the tests run on the 312-in. long steel model, it was necessary that the lower and upper lateral bracing be removed and replaced with alternate members of smaller cross-sectional area. In this phase of the fabrication, the problem arose of making a choice of solders having a lower remelt temperature than the special silver alloy which was used in the assembly of the two stiffening trusses and the floor beams. The low remelt temperature was required because it was desired that all silver brazed joints would not be affected by the heating and assembly of the lower and upper laterals. In addition, an adequate bond strength was desired so as not to have the filler metal fail when the model was loaded.

From tests run on the Princeton model it was determined that a maximum axial force of 1000 lb was developed in the laterals; the homologous force that would be developed in the brass model was calculated as 24 lb. Again tests were run similar to those previously described for the special silver alloy and from the results it was decided that a special lead-tin solder No. 154, with corresponding flux, was most desirable. Its remelt temperature is approximately 378° F which is considerably below that of 1120° F for silver brazing-type alloy used on the brazed joints; further, it had sufficient strength to perform the function as filler metal for the lateral bracing.

With choice of solder made for attaching the lower and upper laterals the jig was revamped. The same plywood board covered with transite board, to withstand heat from the acetylene torch, was utilized for this purpose. The model now consisting of the two main vertical trusses and floor beams was attached firmly to the board in an inverted position and all the lower laterals were inserted.

The joints were all wiped with the corresponding special soldering flux and then heated with a small gas torch and the solder applied. Figures 4 and 5 show representative joints in the main truss, and in the lateral system, respectively. Figure 6 is a view of the brass model completed and ready for testing.

A comparison of the time and cost of the brass model and the steel model is tabulated below:

	Cost, material and labor	*Cost, material*	*Man, hours*
Steel model	$5500	$1500	6000
Brass model	$ 500	$ 55	450

It is concluded that the use of the special silver brazing-type alloy and the special solder because of their unique surface alloying characteristics and their corresponding fluxes helped materially in the assembly of the brass model. The ease with which the solder

flowed onto the brass cut the time of assembly down to a minimum. In addition, the final soldered joints presented neat and clean surfaces.

The primary object of the torsion tests to be run on the brass model is to try and obtain results within 10 to 15% of those obtained on the Princeton model. A series of tests performed on the brass model indicates an excellent correlation between the two models.

The use of small spatial structural models of the type described herein is rare in the field of structural model analysis. It is believed that one of the major reasons for this situation is the difficulties encountered in finding suitable connectors which will enable a number of members in space to be connected adequately and simply at joints. More accurate structural analyses can be effected and much time and money can be saved through the use of such easily assembled models. If the entire series of tests that are contemplated for the brass model results in as good a correlation as the initial tests, then it is entirely conceivable that a new approach in the use of space structural models will be introduced.

Metal Bellows

THE largest metal bellows ever manufactured—as high as a three-story house—have been built by Solar Aircraft Co. in San Diego for a supersonic wind tunnel in Cleveland.

The huge stainless steel expansion joints, which will allow the wind tunnel to "give" when under the stress of air pressure or heat, will be installed in a National Advisory Committee for Aeronautics wind tunnel. A total of 13 expansion joints were built by Solar for this project, ranging from 5 to 28 ft in diameter. The entire order, valued at more than $200,000, weighed 50 tons when ready for shipment.

Solar used special forming and welding techniques in fabricating the bellows, which consist of stainless steel convolutions—to allow expansion and contraction when built into the wind tunnel—joined to carbon steel pipe ends. The company believes the largest previous bellows were 13 ft in diameter.

Far too large to be delivered by truck or rail, the expansion joints were shipped from San Diego to Cleveland by a carefully planned water route. They were loaded aboard a special barge in San Diego Bay, and towed to San Pedro, where they were put aboard the S.S. *President Tyler*. That ship will transport the bellows to New York via the Panama Canal. In New York the bellows will again be placed on a barge, towed up the Hudson River through the New York Steam and Barge Canal to Lake Erie, and then to Cleveland. The last stage of the journey will be handled by professional house movers, to the site of the NACA wind tunnel, near the Cleveland airport.

Since the expansion joints are flexible, unusual precautions were taken in packing them for shipping. The larger units had steel braces welded to the end flanges as stiffeners, and were then placed in huge crates built of 12 in.-square timbers 30 ft

in length. The crates were then reinforced with $^1/_2$-in. steel plates and held together with large bolts. Crating the shipment cost more than $6000, of which $500 was spent on the large nuts and bolts. Fences were dismantled at the Solar plant to move the bellows out of the yard.

Solar manufactures these large stainless expansion joints to cope with pipe expansion at elevated temperatures. In addition to wind tunnels, the large units are used in a variety of industrial processes —refineries, food processing plants, petrochemical installations, atomic energy plants, power plants and other applications where temperature, pressure, corrosion or erosion are problems.

The company also manufactures in very large volume the miniature versions of these jumbo-sized expansion joints—tiny flexible joints, as small as $^1/_2$ in. in diameter, for use with jet engines and other aircraft applications.

EDITORIAL PREVIEWS

Magnesium Ramp

THE latest equipment development in the fast growing "piggy-back" movement of highway trailers by flat cars was announced by Miles L. Abel, executive vice-president of Magnesium Company of America, East Chicago, Ind. Abel reported the development and manufacture of a portable magnesium ramp (Traileramp) to facilitate the loading and unloading of highway trailers from flat cars.

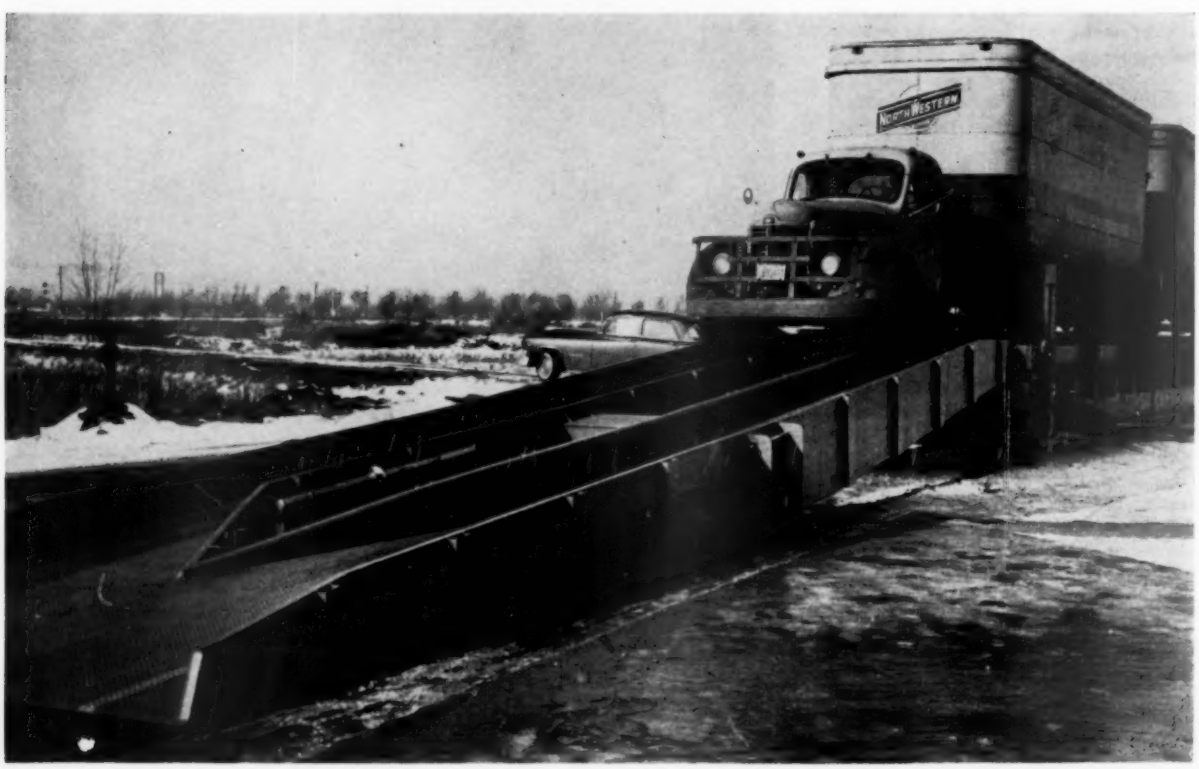
The ramp was developed in conjunction with Brandon Equipment Co., Chicago railway supply and engineering firm, to add speed and flexibility to the existing railroad practice of loading trailers over a fixed, permanent ramp onto flat cars. This practice commonly is called "end loading," said Abel, because all the trailers must pass over this fixed ramp onto the first flat car and then be moved to the next car and so on until the complete string of cars is loaded. A fixed ramp must be located at the end of a stub or dead-end track.

Abel asserted that the ramp enables the railroad to obtain a high degree of selectivity in picking out the trailers it desires to unload first. This feature certainly will reduce some of the materials handling problems that "piggy-back" freight service has created, and will help insure the speeding of freight to the consignees' doors.

"The ramp, of welded construction, is the largest single unit ever fabricated from magnesium, the lightest of the structural metals," said Abel.

The 45-ft-long Traileramp is 9 ft wide but flares to 11 ft at ground level to permit easy approaches and turns by the trailers. Weighing only 4800 lb, the ramp's capacity is designed to take the heaviest loaded trailer. When positioning the ramp with the flat car, it is raised or lowered by means of a simple manually operated hydraulic system. Anchor stakes fit into pockets on the end of the flat car to secure the ramp.

The ramp moves on rubber-tired wheels, and is equipped with a detachable tow bar for attachment to a standard tractor to facilitate its movement in the rail yard. The use of magnesium permits positioning of this 45-ft ramp by two men. Nine-inch-high curbs on the ramp are designed to prevent runoff and excessive tire wear.



Magnesium ramp

the AMERICAN WELDING SOCIETY

activities • related events

AWS NATIONAL SPRING MEETING

May 4–7, 1954 **Buffalo, N. Y.**

Special Events

Plant Visits

Thursday, May 6th—9:00 A.M. to 12:30 P.M.

Your choice of three good plant tours:
Bethlehem Steel Corp.
Westinghouse Electric Corp. (motors and controls)
Ford Stamping Plant

Transportation, by buses, will be provided from the Hotel Statler to the plants and return.

Ladies' Entertainment

Tuesday, May 4th, 3:00 P.M. to 5:00 P.M.

Tea at Hotel Statler

Wednesday, May 5th, 4:00 P.M. to 10:30 P.M.

Buses will leave Hotel Statler and tour beautiful, scenic Niagara Falls. Dinner will be held at Canada's famous Hotel General Brock to be followed by view of Falls at night and return to Hotel Statler.

Thursday, May 6th, 1:00 P.M. to 3:30 P.M.

Buses will leave Hotel Statler for trip to famous and unusual Sattler's Department Store and return to Hotel Statler.

BE SURE TO ATTEND THE AWS TECHNICAL MEETING AND WELDING EXPOSITION

BUFFALO, N. Y. MAY 4–7, 1954

Spring Meeting

Thirty-nine papers on various aspects of welding will be read at the National Spring Meeting of the AMERICAN WELDING SOCIETY, to be held at the Hotel Statler, Buffalo, N. Y., May 4–7, it was announced recently by Fred L. Plummer, President. The Spring Meeting will be held in connection with the second Welding Show, at the Memorial Auditorium, where the most elaborate display of welding equipment and accessories ever assembled will be on exhibition.

Thirteen basic subjects will be covered and three papers will be included in each group. Welding engineers and production and maintenance executives from all parts of the country are expected. Virtually every major industry in the United States and Canada is expected to be represented at both conference and show.

Major topics to be covered are weldability, inert arc welding, resistance welding, welding of stainless steel, surfacing and metallizing, pressure vessels and penstocks, welding of titanium, structural welding, welding processes and equipment, welding of nonferrous metals, welding of piping and tubing, welding applications and a session on welding supervisory education.

In addition to the displays of new types of equipment and the meeting sessions, visitors will be taken on tours of modern plants in the Buffalo and Niagara Falls area to see practical, working methods of welding.

The technical sessions together with the displays at the convention will provide the entire welding industry with an opportunity to obtain first hand the latest information on new products, processes and applications in the welding field.

Visitors who wish to obtain advance registration cards and hotel reservations should write the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y.

Admiral Jelley and President Plummer Address Buffalo National Dinner

Admiral J. F. Jelley, Director of Construction, U. S. Department of Defense, will address AWS members and guests at the AWS National Dinner on Tuesday evening, May 4, 1954, in the Hotel Statler, at Buffalo, N. Y., on the occasion of the AWS National Spring Meeting and Welding Exposition

The Admiral's talk will be titled "Builders Abroad." He was active in several war theaters and his address will encompass interesting experiences from Point Barrow, Alaska, to the Philippines as well as Ankara, Turkey, and the European Far East. Admiral Jelley was then Chief of the Bureau of Yards and Docks, Department of the Navy, and the youngest man ever to be made Bureau Chief. His address will touch upon subjects of interest to both the welding industry and their accompanying ladies.

The brief introductory address will be given by President Fred L. Plummer, the subject being "Welding in Today's and Tomorrow's World." He will point out the way welding will help to make possible the tremendous advances which will be made in every field of construction, affecting the lives of all those now living and of their children.

AWS Members and Guests are urged to mail at once their single, double, group or table dinner reservations, by letter, so that they will hear these vital and interesting talks.

Send letter reservations to National Secretary, AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y., accompanied by check or money order.

Dinner
$10 per plate (Person)
Addresses Music
Entertainment

Tentative Technical Program

AWS National Spring Meeting

Statler Hotel, Buffalo, N. Y.

May 4—7, 1954

TUESDAY AFTERNOON, May 4

Two Simultaneous Sessions

Chairman—CLARENCE E. JACKSON
Electro Metallurgical Co.

Co-Chairman—J. R. HENRY
Cleveland Diesel Engine Division

1—WELDABILITY

A. **Effect of Electrode Type in the Notch Slow Bend Test**
by WILLIAM J. MURPHY and R. D. STOUT, Lehigh University

B. **Effect of Thermal Activation on the Fatigue Life of Butt-Welds**
by A. M. FREUDENTHAL and ROBERT HELLER, Columbia University

C. **Temperature-Tensile Characteristics of Metal-Arc Weld Metal**
by JULIUS HEUSCHKEL, Westinghouse Electric Corp.

Chairman—R. W. BENNETT
American Locomotive Co.

Co-Chairman—W. H. WOODING
Philadelphia Naval Shipyard

2—INERT ARC WELDING

A. **Shielded-Inert-Gas Metal Arc Welding Carbon Steel—Application Data**
by J. R. CRAIG, Linde Air Products Co.

B. **Inert-Gas-Shielded Tungsten-Arc Spot Welding**
by C. A. McCLEAN, Air Reduction Sales Co.

C. **Interrelated Factors in Process Adjustment for Inert-Gas-Shielded Arc Welding**
by EUGENE B. LaVELLE, General Electric Co.

WEDNESDAY MORNING, May 5

Three Simultaneous Sessions

Chairman—JACK OGDEN
Fisher Body Division, GMC

Co-Chairman—JOHN J. MacKINNEY
The Budd Co.

3—RESISTANCE WELDING

A. **Spot Welding Thin Gauge Aluminum Alloys**
by I. W. JOHNSON, General Electric Co.

B. **Single Phase Spot Welding of Aluminum Alloys to MIL-W-6860 Specification**
by J. F. HARRIS, Taylor Winfield Corp.

C. **Flash Welding of Copper to Aluminum Tubing**
by W. F. HAESSLY, Taylor Winfield Corp.

Chairman—H. H. BROWN
Eastman Kodak Co.

Co-Chairman—R. M. WILSON, JR.
International Nickel Co., Inc.

4—STAINLESS STEEL

A. **Performance of Modified Type 347 Weld Metals in Qualification Test**
by L. K. POOLE and R. D. THOMAS JR., Arcos Corporation

B. **Determination of Ferrite in Type 347 Stainless Steel Weld Deposits**
by W. L. FLEISCHMANN, General Electric Co.

C. **The Production of Welded Stainless Steel Pipe**
by A. GRODNER, Alloy Fabricators Division

Chairman—A. N. KUGLER
Air Reduction Sales Co.

Co-Chairman—R. J. McWATERS
Metallizing Engineering Co., Inc.

5—SURFACING AND METALLIZING

A. **Improved Semi-Automatic Welding and Hard Facing**
by HOWARD S. AVERY, T. G. BRASHEAR, H. J. CHAPIN and G. H. EDMUNDS, American Brake Shoe Co.

B. **Fatigue Tests of Steel Specimens Prepared for Metallizing**
by R. C. MILLER, JR., and A. W. BRUNOT, Thomson Laboratory, General Electric Co.

C. **Effect of Welding Variables on Hardness and Abrasion Resistance of Hardsurfacing Deposits**
by A. J. ZVANUT and V. PETERS, The Lincoln Electric Company

WEDNESDAY AFTERNOON, May 5

Three Simultaneous Sessions

Chairman—JOHN F. RANDALL
Ford Motor Co.

Co-Chairman—R. T. GILLETTE
Retired

6—RESISTANCE WELDING

A. **Series Spot Welding of Auto-Body Steel**
by E. F. NIPPES and F. H. DOMINA, Rensselaer Polytechnic Institute

B. **Resistance Welding of Galvanized Steel Tanks—Quality and Production Method**
by J. A. BRADLEY, Rheem Manufacturing Co.

C. **Interpretation of Standards for RWMA Type A-1 Transformers as a Basis for Correct Application**
by J. F. DEFFENBAUGH, F. E. MURRAY and V. A. RATHFELDER, Federal Machine and Welder Co.

Chairman—GEORGE M. TREFTS
Farrar and Trefts

Co-Chairman—H. O. HILL
Bethlehem Steel Co.

7—PRESSURE VESSELS AND PENSTOCKS

A. **30-Ft. Diameter All-Welded Test Tank—Some Unique Design Features**
by JOHN VASTA and F. W. DUNHAM, Bureau of Ships, Navy Department

B. **Automatic Horizontal and Vertical Welding of Field Erected Structures**
by AMEL R. MEYER, Graver Tank & Manufacturing Co.

C. **The Fabrication and Welding of Steel Penstocks**
by R. F. SCOTT, Horton Steel Works Limited

Chairman—T. EMBURY JONES
Precision Welder & Flexopress Corp.

Co-Chairman—PROF. C. E. MARTIN
Purdue University

8—WELDING SUPERVISORY EDUCATION

A. **Welding in Construction**
by J. STEINBERG, New York City Community College

B. **Welding Extension Courses**
by J. FISHER, Penn State University

C. **Industrial Institute Training**
by M. D. THOMAS, General Motors Institute

D. **Resistance Welding**
by J. B. WELCH, Cutler-Hammer, Inc.

THURSDAY MORNING, May 6

Three Simultaneous Sessions

Chairman—W. L. WARNER
Watertown Arsenal

Co-Chairman—R. C. FREEMAN
General Electric Co.

9—TITANIUM

A. **Embrittlement of Titanium Heat-Affected Zones by Air Contamination**
by C. E. HARTBOWER, D. M. DALEY, JR., and W. P. HATCH, Jr., Watertown Arsenal

B. **The Effect of Alloying Elements on Welds in Titanium. Part II**
by G. E. FAULKNER, Battelle Memorial Institute

C. **High-Temperature Alloy Fusion Brazing for Titanium and Titanium Alloys**
by ROGER A. LONG and ROBERT RUPPENDER, Aircraft Components Division, Ferrotherm Co.

Chairman—GORDON CAPE
Dominion Bridge Co. Ltd.

Co-Chairman—LaMOTTE GROVER
Air Reduction Sales Co.

10—STRUCTURAL

A. **Special Problems in Structural Welding for Bridges**
by STEWART MITCHELL and ARTHUR L. ELLIOTT, California Division of Highways

B. **The Reconstruction of the MacArthur Bridge**
by NED L. ASHTON, State University of Iowa

C. **New Principles for the Calculation of Welded Joints**
by PROF. C. G. J. VREEDENBURGH, University of Delft

Chairman—CHAS. H. JENNINGS
Westinghouse Electric Corp.

Co-Chairman—L. S. McPHEE
Whiting Corp.

11—PROCESS AND EQUIPMENT

A. **Manually Guided Submerged Arc Welding**
by R. A. KUBLI, Linde Air Products Co.

B. **Selection of D-C Arc Welding Power Sources**
by A. U. WELCH, General Electric Co.

C. **D-C Arc Welders—Rectifiers or Motor Generator Sets?**
by S. OESTREICHER, Harnischfeger Corp.

FRIDAY MORNING, May 7

Three Simultaneous Sessions

Chairman—W. L. BURKHARDT
Air Reduction Sales Co.

Co-Chairman—A. M. SETAPEN
Handy & Harman

12—NONFERROUS

A. **Brazing Molybdenum for High-Temperature Service**
by M. I. JACOBSON and D. C. MARTIN, Battelle Memorial Institute

B. **Welding of 90/10 Copper-Nickel Alloy**
by G. R. PEASE and T. E. KIHLGREN, International Nickel Co.

C. **Adhesive Bonding Complements Soldering and Brazing**
by H. H. SIMONS, Eutectic Welding Alloys Corp.

Chairman—VINCENT T. MALCOLM
The Chapman Valve Mfg. Co.

Co-Chairman—G. FITCH CADY II
Cady Metal Fabricating Co.

13—PIPING AND TUBING

A. **Validity of Radiography in Predicting Pipeline Joint Strengths**
by RICHARD C. WILEY, California State Polytechnic College

B. **Consumable Insert Method of Root Pass Welding**
by T. A. RISCH and ALFRED E. DOHNA, Electric Boat Division, General Dynamics Corp.

C. **Welding Procedure for Welding Tubes in Heat Exchangers**
by W. E. BATTLES, Leader Iron Works, Inc.

Chairman—DAVID SWAN
Electro Metallurgical Co.

Co-Chairman—H. J. BICHSEL
Westinghouse Electric Corp.

14—APPLICATIONS

A. **Some Practical Considerations in the Application of Tungsten Arc Welding**
by H. A. HUFF, JR., Air Reduction Sales Co.

B. **Industrial Research and Procedure Control as Applied to Automatic Welding Processes**
by WARNER H. SIMON, Dresser Manufacturing Division, Dresser Industries, Inc.

C. **Powdered Metal Electrodes and Their Application**
by J. E. HINKEL, The Lincoln Electric Company

Partial List of Welding Show Exhibitors

Buffalo Memorial Auditorium, May 5–7

BOOTH

ACETOGEN GAS CO. 43
20137 Sherwood Avenue
Detroit 34, Mich.
Att.—S. H. White, Pres.

AIR REDUCTION SALES CO. 26–32
60 E. 42nd St.
New York 17, N. Y.
Att.—R. C. Casper, Adv. Dept.

ALLOY RODS CO. 165–169
P. O. Box 786
(Lincoln Highway West)
York, Pa.
Att.—E. R. Walsh III, Gen. Sales Mgr.

ALL-STATE WELDING ALLOYS CO., INC. 63
249–55 Ferris Ave.
White Plains, N. Y.
Att.—Richard H. Mendel, Vice-Pres.

ALPHA METALS, INC. 101
P. O. Box 34, Bergen Sta.
Jersey City 4, N. J.
Att.—Harold Hertzog, Vice-Pres.

ALUMINUM COMPANY OF AMERICA 121–123
1501 Alcoa Bldg.
Pittsburgh 19, Pa.
Att.—J. B. Clements

ALUMINUM COMPANY OF AMERICA 121–23
P. O. Box 1012
New Kensington, Pa.
Att.—G. O. Hoglund

THE AMERICAN BRASS CO. 46–47
414 Meadow St.
Waterbury, Conn.
Att.—W. H. Dowd, Exhibit Mgr.

AMERICAN CHAIN & CABLE CO., INC. 150
Page Steel & Wire Division
Bridgeport, Conn.
Att.—M. H. Reed, Asst. Sales Prom. Mgr.

AMERICAN MANGANESE STEEL DIVISION 107–109
389 E. 14th St.
Chicago Heights, Ill.
Att.—N. M. McGuire, Adv. Mgr.

THE AMERICAN PLATINUM WORKS 148–149
231 New Jersey Railroad Ave.
Newark 5, N. J.
Att.—J. F. Thompson, Jr., Sales Mgr.

AMES SPOT WELDER CO., INC. 120
1328 58th St.
Brooklyn 19, N. Y.
Att.—Sidney Schwartz, Gen. Mgr.

AMPCO METAL, INC. 174–175
1745 S. 38th St.
Milwaukee 46, Wis.
Att.—Elmer E. Whitson

DOCKSON GOGGLES
Built for Better Protection
COMPLETE PROTECTION—against sparks, dust particles, chemical splash, glare, and injurious rays. Dockson Goggles, available in over 20 models with a full range of lenses, are shop engineered for your rigid requirements.
REAL COMFORT—Lightweight, easy-sitting, top visibility is yours with Dockson Goggles.
LONG LIFE—Dockson Goggles are BUILT FOR BETTER SERVICE. They will last and last.
YOUR DOCKSON DISTRIBUTOR—a selected specialist, stocks a complete line of Dockson Products to give you fast service and personal attention. We back our distributors 100%.
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WRITE FOR YOUR DISTRIBUTOR'S NAME AND OUR COMPLETE CATALOG OF HEAD AND EYE SAFETY EQUIPMENT.
No. 176
No. 50

	BOOTH
AMPOWER PRODUCTS CO. & ROSS MACHINE TOOL CO. 5737 W. 87th St. Oak Lawn, Ill. *Att.*—A. O. Backen	128
ANDCO, INC. 163 Throne Ave. Orchard Park, N. J. *Att.*—E. A. Bonneville	82
ARCOS CORP. 1500 S. 50th St. Philadelphia 42, Pa. *Att.*—H. E. Snyder, Adv. Mgr.	141–142
ARONSON MACHINE CO. Arcade, N. Y. *Att.*—B. R. Aronson, Vice-Pres.	83
BAY STATE ABRASIVE PRODUCTS CO. 12 Union St. Westboro, Mass. *Att.*—E. W. Farmer, Adv. Mgr.	130–131
BERNARD WELDING EQUIPMENT CO. 10222 Avenue N Chicago 17, Ill. *Att.*—Arthur A. Bernard	162–163
THE BURDETT OXYGEN CO. & AMERICAN INDUSTRIAL SAFETY EQUIPMENT CO. 3300 Lakeside Ave. Cleveland 14, Ohio *Att.*—Norman Carl, Sales Mgr.	110
CAM-LOK DIV., EMPIRE PRODUCTS, INC. Box 98 Cincinnati 36, Ohio *Att.*—R. Senior, Pres.	146
CAYUGA MACHINE & FABRICATING CO., INC. 200 W. Gould Ave. Depew, N. Y. *Att.*—B. E. Long	23
THE CHAMPION RIVET CO. Harvard Ave. & E. 108th St. Cleveland 5, Ohio *Att.*—D. J. Schaefer, Adv. Mgr.	61–62
COAST METALS, INC. 201 Redneck Ave. Little Ferry, N. J. *Att.*—H. V. Kough, Sales Dept.	136–138
CONTOUR MARKER CORPORATION OF CALIFORNIA 1843 E. Compton Blvd. Compton 2, Calif. *Att.*—K. D. Bryant, Pres.	10–11
DOCKSON CORP. 3839 Wabash Ave. Detroit 8, Mich. *Att.*—Harold E. Piggott, Pres.	164
DURO-DYNE CORP. 800 3rd Ave. New Hyde Park, L. I., N. Y. *Att.*—Martin M. Gracer, Sec.-Treas.	118
DYER WELD CORP. 9400 Wilson Road Kansas City 3-E, Mo. *Att.*—H. C. Boeke, Gen. Mgr.	90
EUTECTIC WELDING ALLOYS CORP. 40-40 172nd St. Flushing 58, N. Y. *Att.*—F. F. Roehill, Sales Mgr.	1–3
THE FEDERAL MACHINE AND WELDER CO. Overland Ave. Warren, Ohio *Att.*—F. A. Bodenheim, Jr.	172–173
FERROTHERM CO. 1861 E. 65th St. Cleveland 3, Ohio *Att.*—R. G. Cameron, Sales Mgr.	78
FROMMELT INDUSTRIES 290 Main St. Dubuque, Iowa *Att.*—C. P. Frommelt, Mgr.	113
GAMMA INDUSTRIES, INC. P. O. Box 1469 Baton Rouge, La. *Att.*—H. D. Richardson, Gen. Mgr.	102
GENERAL ELECTRIC CO. 1 River Road Schenectady, N. Y. *Att.*—E. E. Spencer, Apparatus Sales Div.	52–55
GENERAL ELECTRIC CO. 570 Lexington Ave. New York 22, N. Y. *Att.*—C. D. Scott, Sales Prom. Services Dept.	52–55
GOLDSMITH BROTHERS S & R CO. 1300 W. 59th St. Chicago 36, Ill. *Att.*—C. J. Saks, Mgr., Brazing Div.	100
HANDY & HARMAN 82 Fulton St. New York 38, N. Y. *Att.*—F. T. Van Syckel, Adv. Mgr.	44–45
HARD FACE WELDING & MACHINE CO., INC. 742 Hertel Ave. Buffalo 7, N. Y. *Att.*—Harold N. Watson, Gen. Mgr.	79
HARNISCHFEGER CORP. 4400 W. National Ave. Milwaukee 46, Wis. *Att.*—B. Germershausen, Adv. & Sales Prom. Mgr.	7–9
HEATH ENGINEERING CO. P. O. Box 69 Fort Collins, Colo. *Att.*—J. W. Mattingly, Pres.	155
C. B. HERRICK MFG. CORP. 2000 Center St. Cleveland 13, Ohio *Att.*—C. B. Herrick	153
THE HOBART BROTHERS CO. Troy, Ohio *Att.*—E. K. Butterfield, Sales Mgr.	16 & 33
HOLGER ANDREASEN, INC. 703 Market St. San Francisco 3, Calif. *Att.*—W. Risoe, Mgr.	170–171
INDUSTRY & WELDING MAGAZINE 1240 Ontario St. Cleveland 13, Ohio *Att.*—L. P. Aurbach, Exec. Vice-Pres.	4
INDUSTRIAL X-RAY ENGINEERS 6 Woodbridge Ave. Woodbridge, N. J. *Att.*—M. L. Leith, Asst. Mgr., Eastern Div.	84–85
THE INTERNATIONAL NICKEL CO. 67 Wall St. New York 5, N. Y. *Att.*—R. L. Lloyd; Gen. Mgr. of Adv.	158–161
JACKSON PRODUCTS 31739 Mound Road Warren, Mich. *Att.*—B. C. Lee, Sales Dept.	126
THE LINCOLN ELECTRIC CO. 22801 St. Clair Ave. Cleveland 17, Ohio *Att.*—A. W. Sawyer, Asst. to Pres.	86–89
THE LIQUID CARBONIC CORP. Industrial Gas Div. 3100 S. Kedzie Ave. Chicago 23, Ill.	134–135

Att.—F. H. Lewis, Sales Mgr.

LUKENS STEEL CO. 35–36
Coatesville, Pa.
Att.—Richard J. Webster, Adv. Dept.

McKAY CO. 91
1005 Liberty Ave.
Pittsburgh 22, Pa.
Att.—A. J. Smith, Asst. Sales Mgr.

MAGNAFLUX CORP. 40
7300 Lawrence Ave.
Chicago 31, Ill.
Att.—F. S. Catlin, Jr.

MARQUETTE MFG. CO., INC. 116
307 E. Hennepin Ave.
Minneapolis 14, Minn.
Att.—M. H. Potter, Vice-Pres.

METAL & THERMIT CORP. 37–39
100 E. 42nd St.
New York 17, N. Y.
Att.—M. L. Smith, Mgr. Adv. & Sales Prom.

MILLER ELECTRIC MFG. CO. 24–25
718 S. Bounds St.
P. O. Box 798
Appleton, Wis.
Att.—D. R. Warner, Sales Mgr.

NATIONAL CYLINDER GAS CO. 13–15
840 N. Michigan Ave. 64–66
Chicago 11, Ill.
Att.—Norman Strandwitz

NATIONAL TORCH TIP CO. 48
Freeport Road,
Pittsburgh 15, Pa.
Att.—E. Werner, Pres.

NELSON STUD WELDING 176–177
Div. of Gregory Industries, Inc.
E. 28th St. & Toledo Ave.
Lorain, Ohio
Att.—S. E. Lepp, Adv. Mgr.

NORTH AMERICAN PHILIPS CO., INC. 152
750 S. Fulton Ave.
Mount Vernon, N. Y.
Att.—G. A. Garnes, Adv. Mgr.

THE PANDJIRIS WELDMENT CO. 49–51
5151 Northrup Ave.
St. Louis 10, Mo.
Att.—P. M. Sackbauer

PORTER-CABLE MACHINE CO., 56
1714 North Salina St.,
Syracuse 8, N. Y.
Att.—M. V. Nodar, Adv. Dept.

PRECISION WELDER & FLEXO-PRESS CORP. 111–112
138 E. McMicken Ave.
Cincinnati 10, Ohio
Att.—W. E. Klingeman

J. M. RAGLE INDUSTRIES 127
4029 Indiana St.
Kansas City 30, Mo.
Att.—J. M. Ragle

ROBOTRON CORP. 129
21300 W. Eight Mile Road
Detroit 19, Mich.
Att.—S. C. Hinds, Vice-Pres., Sales

ROOT, NEAL & CO. 143
64 Peabody St.
Buffalo 10, N. Y.
Att.—Earl Kammerer

ROSS OPERATING VALVE CO. 156–157
120 E. Gold Gate Ave.
Detroit 3, Mich.
Att.—R. J. Cameron, Pres.

SCIAKY BROTHERS, INC. 132–133
14915 W. 67th St.
Chicago 38, Ill.
Att.—Tom Lonergan, Sales Prom. Mgr.

SELLSTROM MFG. CO. 119
635-649 North Aberdeen St.
Chicago 22, Ill.
Att.—C. E. Dennis, Sales Mgr.

SERVICE DIAMOND TOOL CO. 115
2505 Durdette Ave.
Ferndale 20, Mich.
Att.—Louis Small, Pres.

THE SIGHT FEED GENERATOR CO. 104–105
West Alexandria, Ohio
Att.—E. L. Aukerman, Sales Dept.

SMITH WELDING EQUIPMENT CORP. 139–140
2633 4th St. S. E.
Minneapolis 14, Minn.
Att.—N. N. Canfield, Adv. Mgr.

STERLING ASSOCIATES, INC. 145
82 Beaver St.
New York 5, N. Y.
Att.—F. Biel.

SYLVANIA ELECTRIC PRODUCTS INC. 57
1740 Broadway, New York 19, N. Y.
Att.—C. J. Luten, Adv. Mgr.

THE TAYLOR-WINFIELD CORP. 59–60
1052 Mahoning Ave.
Warren, Ohio
Att.—J. H. Cooper, Chief Sales Eng.

TEMPIL CORP. 144
11 W. 25th St.
New York 10, N. Y.
Att.—M. Marsh, Asst. Sec.

THOMSON ELECTRIC WELDER CO. 124–125
161 Pleasant St.
Lynn, Mass.
Att.—F. L. Brandt, Sales Mgr.

TWECO PRODUCTS CO. 56
1450 S. Mosley
Wichita, Kan.
Att.—Roy W. Poe, Sales Mgr.

UNION CARBIDE & CARBON CORP. 70–77
30 E. 42nd St.
New York 17, N. Y.
Att.—R. W. Boggs

UNION CARBIDE & CARBON CORP. 70–77
32–40 43rd Ave.
Long Island City, N. Y.
Att.—D. G. Stewart, Mgr. Exhibit

UNITED SPECIALTY CORP. 117
Main & Mosby Sts.
P. O. Box 698
El Dorado, Ark.
Att.—R. C. Morrison, Gen. Mgr.

UNITED WIRE & SUPPLY CORP. 147
1497 Elmwood Ave.
Providence 7, R. I.
Att.—J. G. Landrigan, Sales Mgr.

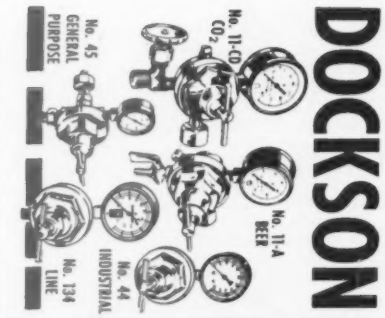
VELOCITY-POWER TOOL CO. 114
201 N. Braddock Ave.
Pittsburgh 8, Pa.
Att.—C. H. Sanderson, Adv. Mgr.

VICTOR EQUIPMENT CO. 103
844 Folsom St.
San Francisco 7, Calif.
Att.—Byron E. Helms, Adv. Mgr.

W. W. ALLOYS, INC., DIV. OF FANSTEEL METALLURGICAL CORP. 34
11644 Cloverdale Ave.
Detroit 4, Mich.
Att.—H. D. Weed, Vice-Pres.

WAGNER MFG. CO. 12
350 W. Adams St.
Jackson, Mo.
Att.—G. C. French, Office Mgr.

WALL COLMONOY CORP. 41–42



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STURDY CONSTRUCTION—Forged brass bodies, shatterproof gauges, dependable safety valves.

LOW COST—Replaceable, self-aligning seats; minimum of moving parts.

YOUR DOCKSON DISTRIBUTOR—a selected specialist stocks a complete line of Dockson Products to give you fast service and personal attention. We back our distributors 100%.

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Dockson CORPORATION
3339 WABASH • DETROIT 8, MICH.

19345 John R St.
Detroit 3, Mich.
Att.—E. J. Lell, Sales Mgr.

The Welding Engineer 58
330 W. 42nd St.
New York, N. Y.
Att.—A. M. Morris, Publisher

WELTRONIC CO. 5
19500 W. Eight Mile Road
Detroit 19, Mich.
Att.—W. H. Smith, Mgr. Sales

WESTINGHOUSE ELECTRIC CORP. 17-22
P. O. Box 868, No. 3 Gateway Center
Pittsburgh 30, Pa.
Att.—P. H. Grunnagle, Gen. Adv. Dept.

New Sustaining Member

The Fairchild Engine Division—with a record of growth and accomplishment going back over a quarter of a century—is today engaged in a variety of design, development and manufacturing projects. More and more the Engine Division is being called on to develop unusual and unconventional power plants. Current engineering contracts range from propulsion systems for underwater ordnance to responsibility for design and construction of the nation's first midget submarine. Gas turbine production for guided missiles and other applications, auxiliary power plants for aircraft and major components for larger jet engines, are included in manufacturing schedules in plants located at Farmingdale, Valley Stream and Mineola, N. Y., the former plant containing executive offices and extensive laboratories and engineering facilities.

A. T. Gregory—Sustaining (A) Member Representative.

DON'T FAIL TO COME TO THE AWS TECHNICAL MEETING AND WELDING EXPOSITION

BUFFALO, N. Y. MAY 4–7, 1954

PRODUCTION BENCH FIXTURE
$30 COMPLETE

REGULAR WELDER
$15.00 COMPLETE

Either unit used to CADWELD
all CADDY arc welding accessories to the arc welding cable

Send today for your FREE "CADDY" ARC WELDING ACCESSORY CATALOG

ELECTRODE HOLDERS, GROUND CLAMPS,
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TUNGSTEN ELECTRODES

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Sylvania Booth No. 57

MEMORIAL AUDITORIUM

Buffalo, N. Y., May 5th, 6th and 7th

Learn about Sylvania's 3 different types of tungsten electrodes. Packaged for your convenience and made to meet the complete requirements of any inert gas arc welding work.

Come and see how and why and where they'll save you time and real money.

SYLVANIA

LIGHTING · RADIO

ELECTRONICS · TELEVISION

Sylvania Electric Products Inc., 1740 Broadway, New York 19, N. Y.

NEW LITERATURE

Some Unsolved Problems

A booklet has been published by the ASTM entitled "Some Unsolved Problems," and is a compilation by ASTM's Administrative Committee on Research intended to stimulate studies of those properties of materials concerning which information is needed.

Copies of this 24-page booklet are available, without charge, from the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa.

Metallurgy of Welding

This book by Walter H. Bruckner consists of 290 pages and is published by the Pitman Publishing Corp., 2 W. 45th St., New York, and sells for $6.00. It is an outstanding textbook concerned mainly with welding from the metallurgical viewpoint. A list of chapters follows: Chapter 1, Heat Flow in Metals; Chapter 2, Metallic Arc Welding; Chapter 3, Torch Welding with Gases and Gas Cutting; Chapter 4, Arc Welding with Carbon and Tungsten Electrodes, Protective and Inert Gases; Chapter 5, Pressure Welding; Chapter 6, Thermit Welding; Chapter 7, Resistance Welding; Chapter 8, Bonding with Brazing, Bronze and Eutectic Alloys; Chapter 9, Surface Treatments: Hard Facing, Flame Hardening and Metal Spraying; Chapter 10, Residual Stresses, Distortion and Stress-Relieving Methods; Chapter 11, Specifications for Base Metal, Electrodes and Welding Rods; Chapter 12, Weldability of Metals; Chapter 13, The Economics of Welding and Design. Also, Appendix 1, Metallurgical Principles; Appendix 2, Special Digests of Welding Literature; Appendix 3, General Reference Books; and Appendix 4, National Standardizing Agencies.

WRC Bulletin No. 17

The Welding Research Council has just issued Bulletin No. 17 of its Bulletin Series. This Bulletin is entitled, *A Critical Survey of Brittle Failure in Carbon Plate Steel Structures Other Than Ships*, by Prof. M. E. Shank, Department of Mechanical Engineering, Massachusetts Institute of Technology. This report was prepared for the Committee on Ship Structural Design, of the National Academy of Sciences—National Research Council. The Committee on Ship Structural Design is advisory to the Ship Structures Committee which supported the project as part of its research program.

No similar correlation on nonship failure data exists, and this survey was therefore undertaken in order to supplement the study of ship failures.

Copies of this 48-page Bulletin may be ordered from the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y. Price $2.00.

Lightweight Pipe

As a practical help to pipe users, Naylor Pipe Co., Chicago, has just issued a new bulletin, No. 507, showing typical applications of its lightweight lockseam-spiralweld pipe and fittings. Included are standard specifications on pipe from 4 to 30 in. in diameter, together with data on fabricated fittings, flanges and connections to meet all pipe-line requirements. Copies may be obtained direct from Naylor Pipe Co., 1230 E. 92nd St., Chicago 19, Ill.

Chromium-Molybdenum Steels

This is the second in a current series of reports prepared under the auspices of the Data and Publications Panel of the ASTM-ASME Joint Committee on Effect of Temperature on the Properties of Metals. This report is a graphical summary of the elevated-temperature strength data for the chromium-molybdenum steels. It includes summary curves for tensile strength; 0.2% offset yield strength; per cent elongation and reduction of area; stresses for rupture in 100, 1000, 10,000 and 100,000 hr; and stresses for the creep rates of 0.0001 and 0.00001% per hr (1% in 10,000 and 100,000 hr); and Larson-Miller master curves (sometimes called the "parameter" method).

The very important Appendix contains the primary data from which the summary curves were prepared, and it is highly recommended that the data sheets be referred to when using the curves. The data sheets also include the chemical composition, processing data, heat treatment and other pertinent information about the steels included in this survey. Among the compositions covered with charts and tables are: $\frac{1}{2}$Mo, NiCrMo, 1Cr – $\frac{1}{2}$Mo, 1Cr – MoV, $1\frac{3}{4}$ Cr – $\frac{1}{2}$Mo, 2Cr – $\frac{1}{2}$Mo, $2\frac{1}{4}$Cr – 1Mo, 3Cr – 1Mo, 5Cr – $\frac{1}{2}$Mo, 5Cr – MoTi, 5Cr – MoSi, 7Cr – $\frac{1}{2}$Mo and 9Cr – 1Mo.

This very important publication contains 200 figures, including summary curves for 23 steels, and more than 250 data sheets for 52 steels.

Copies of this 212-page report can be obtained from Headquarters of the American Society for Testing Materials, 1916 Race St., Philadelphia 3, Pa., at $4.75 each, in heavy paper cover.

Stud-Welding Equipment Chest

Of interest to engineers, contractors and others concerned with stud welding is a specification sheet offered by KSM Products, Inc., Merchantville, N. J., describing in detail a new portable steel chest designed to hold a complete set of KSM stud-welding equipment. Illustration of chest shows packing arrangement to transport KSM control unit, stud-welding gun and accessories, miscellaneous equipment and orders or other papers relating to stud-welding jobs in hand.

Stainless Steel

Armco Steel Corp. has issued a 4-page folder describing its stainless steel "library." Included in the literature is a 44-page general catalog; booklets on stainless steels for heat resistance; the ELC stainless types; ultra thin-gage stainless; handbooks on drawing, forming, spinning and cutting; welding stainless steels; surface finishing; machining, heat treating, forging and pickling; and a number of others.

According to Armco, the purpose of these booklets is to help the user select the right grade of stainless steel and to fabricate it at low cost. Copies of the "Stainless Steel Library" may be obtained by writing to Product Information Service, Armco Steel Corp., Middletown, Ohio.

Economy and Quality Bulletin

The Arc-Welding Division of Ampco Metal, Inc., has just released its new Bulletin W-25 as a guide to economy for metal products. It actually points out that through the proper maintenance and repair, prolonged life and increased quality may be obtained very economically.

It describes the various characteristics

TO BUILD FAITH IN OUR CHILDREN...
TAKE THEM TO SUNDAY SCHOOL

Laymen's National Committee, Hotel Vanderbilt, New York 16, N.Y.

NATIONAL SUNDAY SCHOOL WEEK APRIL 12-18

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Low Temperature EUTECTIC WELDING ALLOYS

and properties of Ampco-Trode, Grades 10, 160, 200, 250 and 300, as well as the Phos-Trode line. Electrode sizes and conforming specifications of these grades are also included.

Each grade description is followed by a list of specific applications recommended for that particular grade. In some of the captions of the 13 pictures, which show typical product examples are actual recorded figures of how much was saved for specific jobs.

Write to Ampco Metal, Inc., 1745 S. 38th St., Milwaukee 46, Wis., for a copy of Bulletin W-25.

Flame Cutting for Weldments

A new 12-page booklet, entitled "Advanced Automatic Flame Cutting for Machinery Weldments," is being offered by Air Reduction.

Reprinted from THE WELDING JOURNAL this article relates how the Marion Power Shovels Co. converted from castings and riveted structures to weldments and discusses the problems involved in making this change, tracing the development and utilization of chain-type flame cutting in the fabrication of these units for power shovels. It tells how, using the electronic tracer, to improve flame-cutting flexibility and increase production capacity while reducing the cost of flame-cut parts and steel plate items for these weldments.

Request a copy of this article by writing to Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Tentative Specifications for Copper and Copper-Alloy Welding Electrodes

Five types of copper and copper-alloy covered and bare electrodes are described in the new edition of the *Tentative Specifications for Copper and Copper-Alloy Welding Electrodes* just issued jointly by the AMERICAN WELDING SOCIETY and the American Society for Testing Materials (AWS Designation A 5.6; ASTM Designation B 225). The new edition of this specification was prepared primarily to standardize the electrodes used in inert-gas metal-arc welding, which is gaining wider use in the copper field daily.

The filler metals covered include copper; copper-silicon (silicon bronze); copper-tin (phosphor bronze); copper-nickel; and aluminum bronze.

A table gives the chemical analyses of the different classifications in each group and standard tests for verifying conformity of a given electrode to the standard requirements. New packaging requirements for inert-gas metal-arc welding electrodes are provided.

The Appendix, which gives information especially helpful to the user in selecting the most suitable filler metal for his application, has been revised to provide the latest information on inert-gas metal-arc welding.

Copies of the *Tentative Specifications for Copper and Copper-Alloy Welding Electrodes* can be obtained at 25 cents each from the AMERICAN WELDING SOCIETY, 33 W. 39th St., New York 18, N. Y., or the American Society for Testing Materials, 1916 Race St.,Philadelphia 3, Pa.

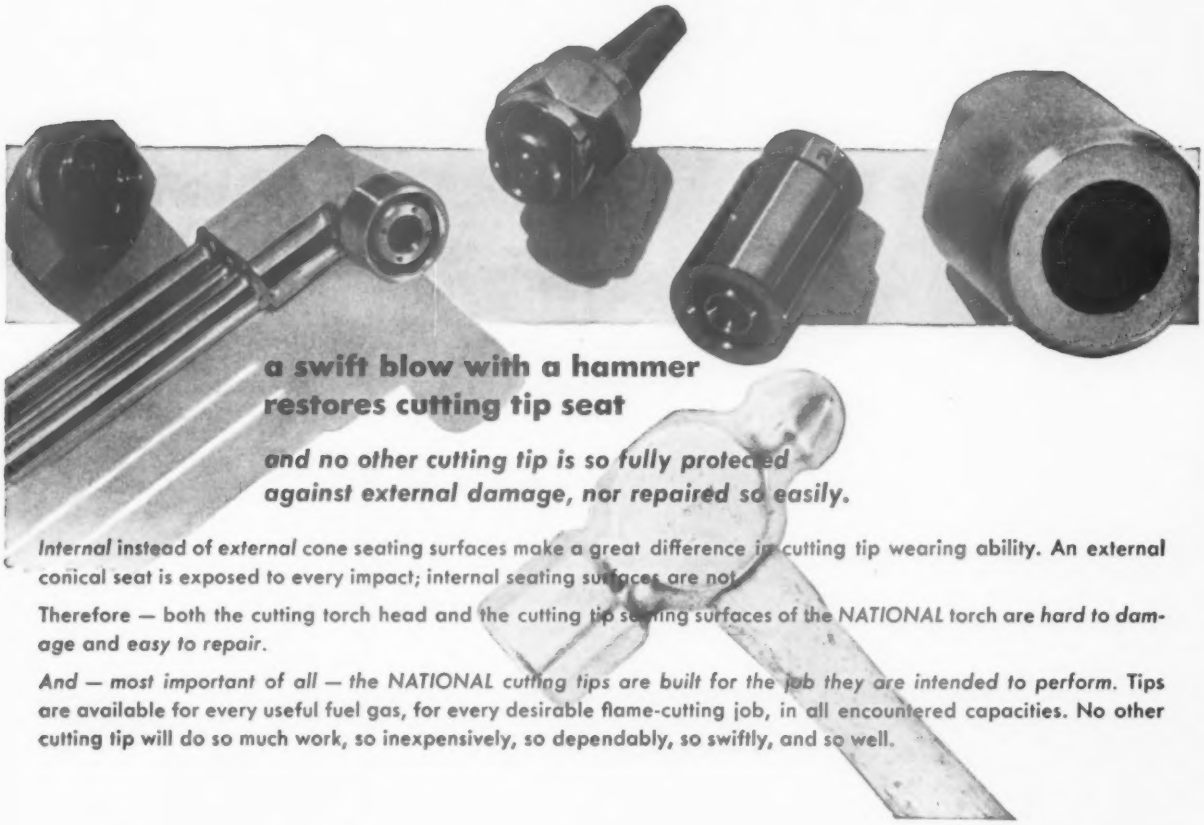
Standard Resistance Welders

Resistance Welding at Work relates the problems of various manufacturers and their solutions through the use of resistance welding. A new edition tells how standard resistance welders have been adapted to do what was previously considered a job requiring special machines. The case cited in *Resistance Welding at Work* is a multiple weld operation on automobile bumper guards. The principle, however, is adaptable to a wide variety of resistance welding jobs—all told in the new issue of the house organ.

Copies of *Resistance Welding at Work* may be obtained from Sciaky Bros., Inc., 4915 W. 67th St., Chicago 38, Ill. Ask for Vol. 3, No. 8. There is no charge.

SEE IT IN ACTION AT THE WELDING SHOW
BOOTHS 124-125
Center of attraction at the Welding Exposition in Buffalo, May 4-7, will be this THOMSON Model F4-250KVA *Synchro-Matic* Flash Welder. See it perform on ferrous metals, non-ferrous metals and dissimilar combinations.
THOMSON ELECTRIC WELDER CO.
LYNN • MASSACHUSETTS
Offices or Agents in all Metalworking Centers
THOMSON SYNCHRO-MATIC FLASH WELDERS
(Patent No. 2,492,200)

here's why this cutting tip lives longer . . .



a swift blow with a hammer restores cutting tip seat

and no other cutting tip is so fully protected against external damage, nor repaired so easily.

Internal instead of *external* cone seating surfaces make a great difference in cutting tip wearing ability. An external conical seat is exposed to every impact; internal seating surfaces are not.

Therefore — both the cutting torch head and the cutting tip seating surfaces of the *NATIONAL* torch are *hard to damage* and *easy to repair*.

And — most important of all — the NATIONAL cutting tips are built for the job they are intended to perform. Tips are available for every useful fuel gas, for every desirable flame-cutting job, in all encountered capacities. No other cutting tip will do so much work, so inexpensively, so dependably, so swiftly, and so well.

even the best cutting torches are inexpensive to buy . . . this one is less costly to keep on the job.

After all, even the best cutting torches cost but little to purchase; how much it costs to keep them on the job is the more important consideration . . .

How many cutting tips will be damaged—how many of them can be restored to full working order—how often does the torch need a trip to the repair man—does it waste or conserve gases—these are among the important questions asked by the purchaser.

And these are the reasons why we talk so much about "internal" rather than "external" conical seating of cutting tips; this is why we emphasize repairability.

. . . no other cutting tip can be reconditioned so easily

Made by National SINCE 1910 **WELDING EQUIPMENT CO.,** San Francisco 5, California

533

PERSONNEL

Comfort Adams Honored

The January 1954 *Magazine of Standards*, which is the official organ of the American Standard Assn., describes the origin of the American Standards Assn. and the part played by Dr. Comfort Avery Adams, founder of the AMERICAN WELDING SOCIETY. In this issue Roger E. Gay, President of the American Standards Assn., said in part:

"As its first act at that first meeting, the Committee elected a very distinguished gentleman as its chairman. He was Dr. Comfort A. Adams, of the Harvard Engineering School, president of the American Institute of Electrical Engineers, and member of The American Society of Mechanical Engineers. The standards movement of this country owes an infinite and unrepayable debt of gratitude to Professor Adams for his wise and patient leadership during the founding years of the national movement."

Professor Adams briefly reviewed the events leading up to the organization of the American Standards Assn. Of special interest is a quotation by Professor Adams in one of the first meetings of the American Standards Assn. Again we quote from the *Magazine of Standards*.

"In one of the first meetings of the American Engineering Standards Association, Professor Adams, the chairman, made this statement: 'I think you cannot fail to see (he said) the tremendous possibilities and value to all industries, and to the nation as a whole, of this work of standardization. . . . If we can inject into other organizations the idea which we have evolved here—the idea of thorough, broad and comprehensive cooperation in the making of standards, then I think we will have accomplished one of the biggest jobs that has ever been undertaken in this country. It would do more to solve some of the present economic problems of the United States than anything else we could do.'

"These are the words of a prophet. They are as true today as when they were spoken 35 years ago. The whole problem and promise of the standards movements is contained in that statement.

Leach Promoted

Austin F. Leach has been appointed manager of product service for the General Electric Co.'s Welding Department, according to C. I. MacGuffie, the department's manager of marketing.

In his new post he will be responsible for developing techniques to reduce maintenance, increasing availability of renewal parts, and for general service to customers on all products of the department.

A native of Texas, Mr. Leach was graduated from the University of Texas in 1941 with a B.S. degree and joined G.E. the same year. First associated with the company's Test Course, he joined the Welding Department as an application engineer in October of 1943.

In 1945 he was named welding sales engineer for the G-E Southwestern and Rocky Mountain districts, and in 1950 was transferred to the department's former location at Fitchburg, Mass., as an electrode sales engineer.

In December of 1952 he was appointed manager of renewal parts, the position he held at the time of his present appointment.

Employment Service Bulletin

Position Vacant

V-308. Application engineer for submerged melt and inert-gas-shielded automatic arc-welding machinery. Substantial experience in application of automatic arc welding desired. Responsibilities include supervision of sale, application, design and use of such machinery. Reasonable amount of travel in USA is necessary. No age limit. Salary open for discussion. All applications accepted in strict confidence.

Services Available

A-649. Welding Engineer—Metallurgist—graduate, 13 years' broad metallurgical experience; specialist in brazing most metals employing fluxes and controlled atmospheres. Ability to conduct laboratory projects and troubleshoot shop problems. Author of papers. Desire position related to peacetime business.

ALLOYS All-State FLUXES

WE'VE GOT TIME ANYTIME TO TRY TO SOLVE YOUR PROBLEM

Welding people have been tossing problems to us for years now. We like it. And, we've successfully found good answers to so many of them that today we can offer you off the shelf:

The world's most complete line of alloys and fluxes for aluminum,

8 alloys and fluxes for work on cast iron,

12 for copper, brass, etc.,

8 for stainless steel,

12 for steel,

Many other alloys and fluxes for magnesium, nickel, zinc-base die cast, tinning, galvanizing, cutting, bevelling, and chamfering

Chances are that we can give you your answer quickly.

Or, perhaps you can find it yourself in our 24-page Buyers Guide.

Showed me how to join nichrome to copper.
Made me the world's strongest soft solder.
Gave me an electrode a beginner can use.
Showed me how to repair heat treated parts without spoiling the temper.

Want a copy? Ask...

ALL-STATE WELDING ALLOYS CO., INC.

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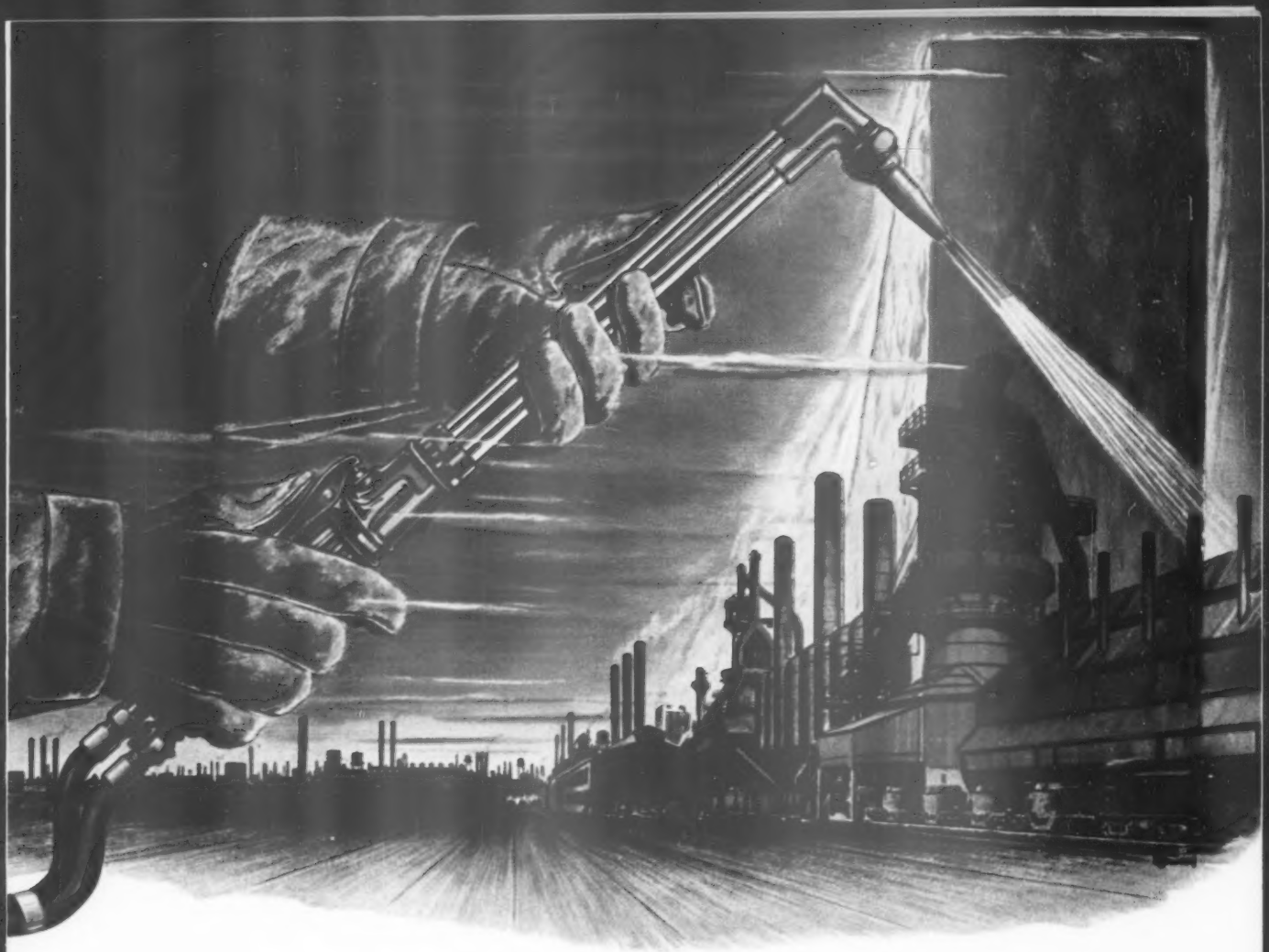
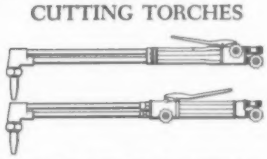
DISTRIBUTORS EVERYWHERE

Booth 63 Welding Show



NO JOB TOO HOT ...OR TOO TOUGH *for THESE cutting torches!* *

* VICTOR'S NEW
Series 1000
Series 1100
CUTTING TORCHES



CHOICE OF LEVER POSITION . . . cutting oxygen lever pivots from top rear of handle on Series 1000; from top front on Series 1100. Both Underwriters' approved. Available with 45°, 75°, 90° or 180° heads, to take all VICTOR standard-type tips.

LICK YOUR HOTTEST JOBS
without a flashback . . . solid stainless steel mixing tube absorbs heat slowly, keeps gases below flashpoint.

LAST LONGER UNDER ROUGH, TOUGH USE
because they're made of toughest materials . . . special heat resisting bronze heads, stainless steel tubes, forged brass bodies.

EASIER TO HANDLE, EASIER TO MAINTAIN
. . . hand-fitting oval shaped bodies, perfect balance give precise control. Design is simplicity itself; you can take either model apart completely, then reassemble it, all in less than 5 minutes!

Make your tough jobs easy, your easy jobs a pleasure — see your VICTOR dealer now!

VICTOR

VICTOR EQUIPMENT COMPANY

Mfrs. of welding & cutting equipment; hardfacing rods; blasting nozzles.

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meeting
and
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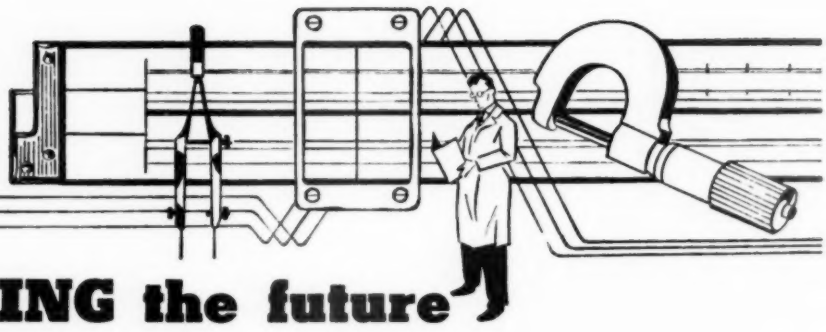
BUFFALO, MAY 4-7, 1954



ENGINEERING the future

The future progress of your industry could well be affected by the National Spring Technical Meeting and Welding Exposition of the American Welding Society.

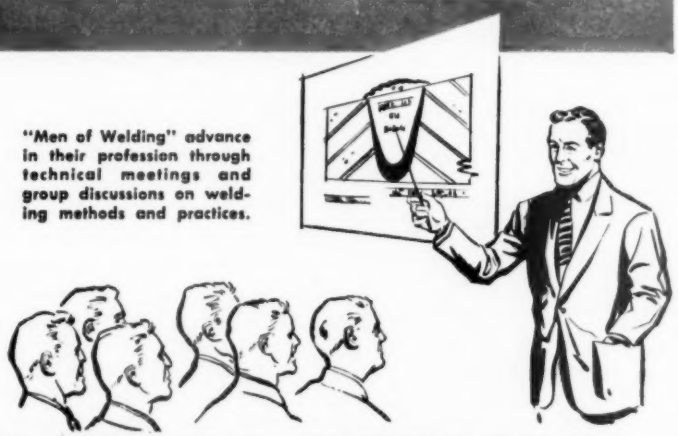
Leading authorities have prepared reports on many phases of welding engineering, procedures, metallurgy, materials selection and plant maintenance. Product design and manufacturing efficiencies will be important subjects of discussion by A.W.S. members and guests in attendance.

If your firm is using production or maintenance welding of any sort, these A.W.S. spring events are important to your management, your supervisors and individual members of your engineering personnel. May we suggest that you consider attending personally or sending a representative?

A. W. S. Builds "MEN OF WELDING"

There are 66 active local sections of A.W.S. covering the entire United States. The 9,683 members of A.W.S. hold monthly technical meetings and plant visitations where they observe practical solutions to typical welding problems and study new welding methods. They receive accurate information on welding design, fabrication and maintenance through discussions with the best welding minds in the nation and authoritative printed reports.

"Men of Welding" advance in their profession through technical meetings and group discussions on welding methods and practices.



AMERICAN WELDING SOCIETY

A powerful force in welding progress since 1919

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Please send me more information on the personal and company advantages of membership in A.W.S.

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NEW

automatic welding
without shake or shimmy

THE PANDJIRIS WELDING HEAD MANIPULATOR

IT PILOTS YOUR WELDING HEAD!

. . . welds are smooth and even! Reason: *Machine tool accuracy* in all moving parts; it's rigid . . . it's compact.

MORE VERSATILE—adapts to any weldment

- Power car moves *up or down* track at selected variable welding speeds. Rapid traverse return.
- Boom travels *in or out* at selected variable welding speeds. Rapid return.
- Boom moves *up and down*. Head lowers to floor level.
- Mast with boom rotates 360° on power car.
- Welding head swivels 180°.

CENTRAL CONTROL PANEL—all tachometers, gages and push buttons mounted together. Panel swings in 90° arc—always visible to operator.

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PANDJIRIS WELDMENT CO.

NEWS OF THE INDUSTRY

Metal and Thermit Office

To better service their customers in the southeastern part of the country, Metal and Thermit Corp., New York City, have opened a District Office in Atlanta, Ga.

Claude Davis, Jr., is in charge of this office, the address of which is 762 Stewart Ave., S. W. Atlanta, Ga.

Stocks of their products are being maintained there and Mr. Davis will be glad to be of assistance to you at any time in connection with Murex Electrodes, M&T Welding Machines and M&T Arc Welding Accessories.

Budd Presents Exhibit to Franklin Institute*

A new exhibit which will show visitors to The Franklin Institute the modern methods used in the manufacture of an automobile body was recently dedicated in brief ceremonies.

Representatives of The Budd Co., sponsor of the display, and Institute officials witnessed the first demonstration. Dr. Henry B. Allen, Executive Vice-President of the Institute, made the first weld on a machine which is a part of the exhibit.

Participating in the dedication were G. E. Lallou, Budd Secretary-Treasurer; J. G. Richard Heckscher, Commercial Products Manager; J. E. Winlock, Chief Metallurgist; and A. D. Leeson, Advertising Manager.

The Budd Co.'s association with The Franklin Institute Museum dates back to the time the Museum was opened. In 1933 the company put on display its stainless-steel airplane, the *Pioneer*, which is today still on exhibit outside the building, 20th St. and the Parkway.

Budd has maintained exhibits within the building for many years which show Philadelphians who visit the Museum the manufacturing story carried on by one of the city's largest industrial employers.

* From *Franklin Institute News*, February 1954.

Lawrence L. Williams

Welder at work: Dr. Henry B. Allen, Executive Vice-President of the Franklin Institute makes the first weld at the new Budd exhibit recently dedicated at the Institute

Welding Conference

The fourth conference on Electric Welding under the sponsorship of the American Institute of Electrical Engineers, in cooperation with the AMERICAN WELDING SOCIETY, has been scheduled for Milwaukee (Wis.) on May 19, 20 and 21 at Hotel Schroeder. The conference is being arranged by the AIEE Committee on Electric Welding. A full program of papers on electric welding and inspection of welding processes in Milwaukee plants will feature the three-day meeting.

E. J. Limpel of A. O. Smith Corp., Milwaukee, and Chairman of the AIEE Committee on Electric Welding, will be in charge of the 1954 meeting. His executive committee consists of the following:

Papers—A. U. Welch, General Electric Co., York, Pa.; *Publications*—H. W. Tietze, Public Service Electric & Gas Co., Newark, N. J. *Publicity*, R. E. Young of Public Service Co., Kankakee, Ill. *Secretary*, R. J. Krieger, Titanium Metals Corporation of America, Henderson, Nev.; *Conference Treasurer*, C. E. Pflug, Nash Motors Division, Nash Kelvinator Corp., Kenosha, Wis.; *Local Chairman*, J. W. Brown, Square D Co., Milwaukee.

Archer Aridair Stabilizer Contest Announced

One of the most interesting house organs in the welding field is being issued by the Fred C. Archer Company, makers of the Aridair Electrode Moisture Stabilizer.

The prime purpose of this new house organ will be to familiarize management, shop men and dealers with the necessity of stabilizing the moisture content of stainless steel and low-hydrogen electrodes.

Records show a good percentage of poor welds can be directly charged to excessive moisture absorbed between the time the hermetically sealed package is opened and the time of actual use. Dangerous moisture content is sometimes developed in a few hours under unfavorable atmospheric conditions.

Moisture and similar related welding problems will be discussed in the Archer Co. publication which will be called *Welding Views*. The first issue will announce a $100 prize for best letter on the use of the Aridair Stabilizer. Both dealers and users are eligible. Contest closes April 15th. For details write the Fred C. Archer Co., 606 W. Wisconsin Ave., Milwaukee 3, Wis.

Eutectic Technical Movie

A motion picture, titled "New Welding Procedures," has been produced by the Eutectic Welding Alloys Corp., Flushing, N. Y., and is now available for distribution. The film is in full color with sound. The company states that to the best of its knowledge this is the first time a fully explanatory, step-by-step film on welding rod and electrode techniques and proce-

Simplified Precision Welder Control

for easier maintenance and increased dependability

Class 8993 NEMA Type S2H Synchronous-Precision Controller available with 600 or 1200 frame contactor. Can be arranged either for side of machine or wall mounting.

DESIGN LEADERSHIP

APPLICATION: *for welding stainless steel, nonferrous metals, and other critical spot welding jobs requiring electronic synchronous-precision control. (Available with current wave shape control auxiliaries for aluminum or alloy metals.)*

DESIGN LEADERSHIP features

Easier Maintenance . . . greatly simplified circuits require fewer tubes and only one operating relay (for the air valve).

Increased Dependability . . . all components designed specifically for industrial welder service. Tube circuits are fail-safe and initiating contacts are in isolated 24 volt circuit which supplies power to the valve relay.

Consistent Accuracy . . . regulated DC voltage on tube control grids compensates for supply fluctuation or tube variations . . . assures timing accuracy.

Greater Accessibility . . . timer, heat control and firing panels designed for easy inspection and maintenance, with quick fasteners and plug connectors.

***Write* for BULLETIN 8993**
or consult your nearby Square D Field Engineer

SQUARE D COMPANY

Page Welding Wire

Now—a new line-up of PAGE welding wire in coils, reels, packages

• Here are some of the ways PAGE welding wires are packaged to protect them during shipment and to make it easy for you to handle and stock them. Two new packages are Leverpaks and pallet-mounted coils.

LEVERPAKS • Here's one of the best containers for coils up to 16" ID. It's light-weight, but durable. It is sealed air-tight and is packed with moisture-absorbing substance to reduce corrosion. Release safety catch, pull lever, and the whole top comes off. It's just as quickly resealed. Leverpaks can be rolled easily. They stack perfectly and take a minimum of floor space. They cost you nothing extra and have many re-uses.

PALLET-MOUNTED COILS • If you have a fork-lift truck, you'll like PAGE'S new pallet-mounting of 22" ID coils. Steel strapping and paper wrapping protect coils and hold them securely. You can run them in and out of freight cars and trucks, and spot them in your plant.

AUTOMATIC WELDING WIRES • **Inert Gas**—Six PAGE-ALLEGHENY stainless grades in .035", .045", and .0625" diameters. Precision thread-wound on 25-lb. non-returnable reels to fit popular arc welding machines. **Submerged Arc**—PAGE Stainless in wire diameters from 1/32" to 5/16", plain or copper coated. In layer-wound coils or 22" or 24" mill coils.

GAS WELDING RODS • In a variety of analyses: stainless, Armco, medium and high carbon, and manganese or naval bronze.

Warehouse stocks in Chicago, Denver, Houston, Los Angeles, San Francisco

Write our Monessen, Pa., office for literature and prices

ACCO

Page Steel and Wire Division

AMERICAN CHAIN & CABLE

Monessen, Pa., Atlanta, Chicago, Denver, Detroit, Los Angeles, New York, Philadelphia, Portland, San Francisco, Bridgeport, Conn.

dures has been offered. The latest developments in torch and metallic arc welding are shown in typical operations. Research and theory go side by side with practice, and indicate how money can be saved in every plant and shop by putting these methods to use. A spectacular rock and concrete piercing electrode, which can be operated with a standard welding machine, is seen in action.

This movie, although of only 19 minutes' duration, includes samples of arc welding in which the principle of "surface alloying" has been incorporated to reduce the heat input to a minimum. Emergency repairs upon machinery vividly show how replacements can be minimized and downtime reduced if the correct welding materials and techniques are used.

It is presented as a public service to industry as a whole in order that all may benefit. The film is available free of charge to all technical societies, schools and colleges, plants, etc.

A 4-page booklet describing the film is available free of charge by writing to: Eutectic Welding Alloys Corp., 40-40 172nd St., Flushing 58, N. Y.

National Welding Supply Assn. Meeting

James N. Alcock, Saginaw Welding Supply Co., 426 S. Washington Ave., Saginaw, Mich., was elected President of the National Welding Supply Assn. at the Association's recently concluded Tenth Annual Convention at the Hotel Fairmont, San Francisco.

Mr. Alcock is a Charter Member of the Association, has been a Director for many years and for the past two years served as vice-president representing the Central Zone. This zone includes the states of Michigan, Illinois, Indiana, Iowa, Ohio and Wisconsin.

In addition, Mr. Alcock has been active in committee activities of the Association,

having chairmanned the important Catalog Committee. This committee recently developed Official Standards for Catalog Pages for Distributor Salesmen and Counter Catalogs for the Welding Industry.

The Association's Tenth Annual Convention was the first ever held on the West Coast and was attended by 375 distributors and manufacturers of welding supplies and equipment from all sections of the United States as well as Canada and Hawaii.

Organized on Sept. 17, 1945, the Association has experienced a rapid increase in Membership until it now is composed of over 400 of the leading distributors and manufacturers of welding supplies and equipment in the country. The objectives of the Association are to promote and maintain such constructive cooperation among welding equipment and supply distributors and their sources of supply as will advance their mutual interests; inspire the observance of high business methods as will make for efficient and profitable operation; encourage adherence to sound policies and practices; all to the end that the welding supply distributors may retain their place and identity as an essential and efficient service in the distribution of welding equipment, supplies and gases.

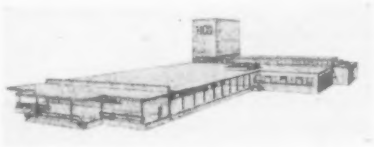
Welding Seminar

The University of Wisconsin recently held a highly successful Welding Seminar at the University at Madison on January 13th to 15th. The Seminar was conducted by the University in their new Engineering Building. Some of the subjects covered were: "Structural Design for Welding," "Machine Design for Welding," "Field Tests and Inspection—Methods of Control," "Codes and Welder Certification," "Silver Brazing and Copper Furnace Brazing," "Welding Metallurgy —Stress Relieving," "Welding Practices," "Welding High Temperature, Pressure and Steam Piping," "Heavy Weldments," "Metal Spraying," "Problems Confronting the Welding Engineer in Resistance Welding," "Designing a Power Source for Consumable Electrode-Gas Process" and "What's New in the Welding Field?"

About fifty enrollees attended the Seminar covering Wisconsin and Northern Illinois.

Liquid Oxygen Plant

National Cylinder Gas Co. announced that it will soon begin construction of a $3,500,000 plant for manufacturing and distribution of liquid oxygen on a site located on the south side of Chicago, just acquired.



Charles J. Haines, president of the company, said the growth in National Cylinder's oxygen business in the Chicago area makes the added production to be obtained from the new plant essential to meet the improving demand.

The plant will be built on an 8-acre tract below 109th and Torrence, formerly known as Irondale. The building, for which foundations will be dug immediately, will be of one-story construction.

The company has a total of 91 oxygen and acetylene plants in the United States, Canada, Colombia and Venezuela.

Ohio State Conference

The first *Annual Conference* for *Engineers* will be held at the Ohio State University on Friday, May 7, 1954.

ACE precedes Alumni Day, Saturday, May 8, 1954—the day of the Spring Football Game in Ohio Stadium.

The morning program will be held in the new, beautiful Ohio Union Building. Charles F. Kettering will speak on "Getting Results from Engineering Research." Another nationally known speaker will address the noon banquet.

University of Wisconsin Welding Seminar

ARCAIR TORCH does big cutting job for GATX

When the maintenance division of General American Transportation Corporation needed a new and better answer to metal cutting problems, they found it in the Arcair Torch.

At the East Chicago repair yard of GATX, the job involved replacement of cast stainless steel doors on hopper cars specially built for transporting corrosive materials in bulk. The one-ton castings had been so badly damaged that it was necessary to cut away cracked and crushed sections and reweld new sections in their place.

All inner surfaces are stainless or stainless-clad steel. Even with extreme care, ordinary methods of cutting resulted in contamination of these surfaces by the formation of carbon or iron deposits.

Using the Arcair Torch to cut stainless steel castings is but one of its many applications at GATX.

With the Arcair method of cutting, using only carbon arc and compressed air, formation of contaminating deposits was negligible. GATX supervisors were more than pleased, too, by the smoothness of the cut. Smooth, even cuts meant easier and faster rewelding without chipping or grinding.

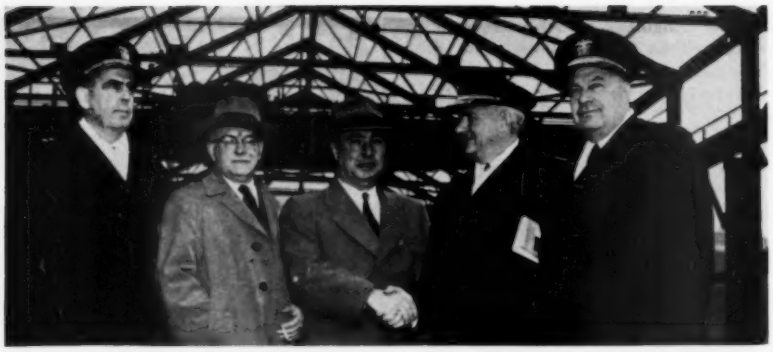
More Arcair Torches have since been ordered for use in other GATX shops for many different jobs. For instance, in the salvage operations of GATX, the Arcair Torch is now used to sever bolsters, couplers, heavy castings and other parts from retired cars. Clean cuts often enable the components to be immediately rewelded to other cars with no grinding or machining.

Many industrial users, like GATX, have found that the Arcair Torch does gouging and cutting jobs at low cost, and results in valuable salvage recovery.

Write for free bulletin with facts and photographs of time and money-saving applications of the Arcair Torch.

ARCAIR COMPANY
EASTERN DIVISION:
P. O. Box 337, Lancaster, Ohio
WESTERN DIVISION:
P. O. Box 4227, Bremerton, Wash.

Arcair TORCH
Cuts all metals—using only electric arc and compressed air



Pictured at the Homestead Works (left to right) are Rear Admiral E. W. Sylvester, of the Navy; David P. Brown, of the American Bureau of Shipping; C. J. Fleisch, assistant general superintendent at Homestead; Admiral Cowart and Capt. W. H. von Dreel, also of the Navy

Ship Structure Subcommittee Meets in Pittsburgh

Under the chairmanship of Capt. J. J. Fee, USN, the Ship Structure Subcommittee met jointly with the Ship Structure Committee and with the Committee on Ship Steel of the National Academy of Sciences, National Research Council, in Pittsburgh on February 24th. This meeting was held at the United States Steel Corp. headquarters and was devoted to discussion of recent research in shipbuilding steel. On February 23rd the group toured the Corporation's Homestead and Irvin works, observing the production of steel plate and sheet. Greeting the Committee, on behalf of the Corporation, were C. F. Hood, President, H. B. Jordan, Executive Vice-President, Operations, and Dr. E. C. Bain, Vice-President, Research and Technology.

Rear Admiral K. K. Cowart, USCG, Engineer-in-Chief, U. S. Coast Guard, is chairman of the parent group, the Ship Structure Committee, which is composed of members from the Coast Guard, Navy Bureau of Ships and Military Sea Transportation Service, Maritime Administration, and American Bureau of Shipping. The Committee was established in 1946 by the Secretary of the Treasury "for the purpose of conducting a research program to improve the hull structure of ships." Besides sponsoring research on shipbuilding materials, the Committee also supports research programs on the design and fabrication aspects of ship construction.

New ASCE Committee on Pipe Lines

The American Society of Civil Engineers recently established, within the framework of its Construction Division, a Committee on Pipelines. The purpose of this Committee is to advance and correlate scientific knowledge, to promote and coordinate economic development and construction of engineering projects in connection with the transmission of fluids, gases or solids by means of pipe lines and as it pertains to the science of Civil Engineering, particularly in the fields of surveying, line location, design, construction and operations.

Another purpose of this Committee is to promote and further the mutual utilization of the established codes for pressure piping as among pipe-line, highway and railroad groups, and public authorities.

The American Society of Civil Engineers and the Committee are very anxious to be of service to all persons who are interested in the activities of this Committee or feel that they can contribute to its work. Those desiring information on the Committee's activities, published reports, etc., should write directly to Wm. N. Carey, Executive Secretary, American Society of Civil Engineers, 33 W. 39th St., New York 18, N. Y.

Niels Miller—Pioneer in a Welding Helmet

It is a commentary on the rapid progress of our times that boys whose chores once included filling kerosene lamps, have grown up to run the vast industry born of electricity. One such boy was Niels Christian Miller, now 56 and heading up the Miller Electric Manufacturing Co., Appleton, Wis. The firm this month celebrates its twenty-fifth anniversary of arc-welding equipment pioneering.

The story of the company's origin and development is colorful and interesting. But most unusual, perhaps, is that after the years of growth, change and achievement, the company still reflects the personality and philosophy of Niels Miller.

Mr. Miller was born Aug. 30, 1898, at Dancy, Wis., the son of a farmer imigrant from Denmark.

Formal schooling was a sort of hit-or-miss affair, but as far as education is concerned that hasn't even stopped today.

He left the farm at 20 and went to work for Menasha Wooden Ware. Shortly after he got a job at the Strange Paper Co. and then at the Gilbert Paper Co.

He spent at least three nights every week studying electricity in Vocational

Niels Miller

Schools. Electricity was a novelty then.

Mr. Miller's next job was at Langstadt Electric Co. in Appleton. He then took a job with the only electrical manufacturing plant in town at that time—the Kurz and Root Co. In less than a year and a half with the company he became head of the testing and assembly line.

About 1924 a fellow came around to the company with the idea that if you could build an engine-driven welder–at a reasonable price—you were going to have a great market for it. Mr. Miller helped design, build and test this new d-c arc welder.

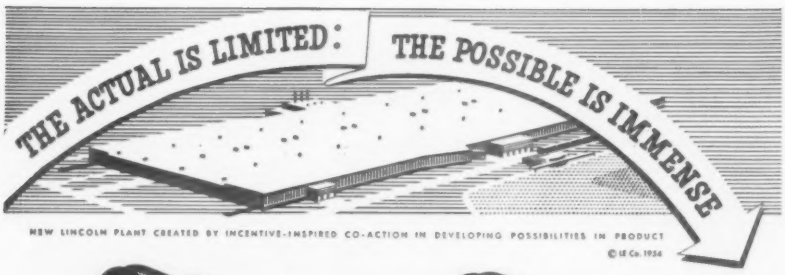
Mr. Miller decided to design a welding transformer. He started with a 4-coil design—2 primary 2 secondary—with a flux diverting block in between the two, wound so that he could either build or reduce the voltage. And that unit could weld even with the electrodes available then—mainly lime coated electrodes and not very good. But his company wouldn't have any part of building this welder.

Mr. Miller took the money he had, and started building welders in his basement in 1929. He ended up in 1932 with about 400 welding machines built in that basement.

And then over the period of years up to the war the new company made three different moves to increase capacity. Mr. Miller also lined up some good sales outlets—the Sight Feed Generator Co., National Cylinder Gas Co. and others.

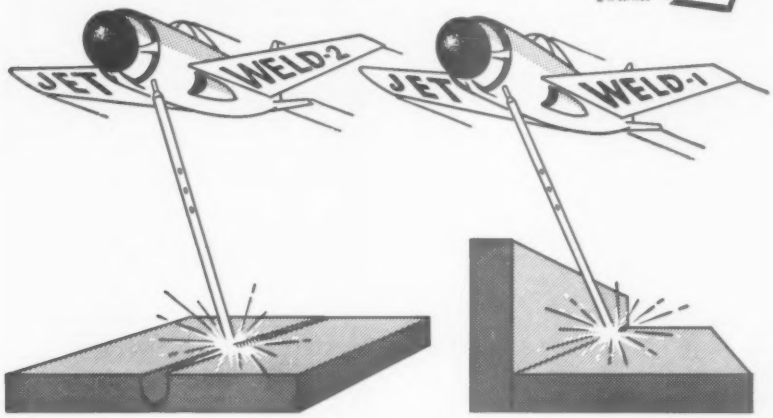
The Miller Electric designed and built a motor generator set welder for National Cylinder Gas. They built the transformer welders that are still known today as the "100 Series." The company built machines for the Una Welding Co.

Mr. Miller believes the biggest market right now is replacing inferior obsolete welding equipment—replacing those machines with Miller rectifier-type welders.



NEW LINCOLN PLANT CREATED BY INCENTIVE-INSPIRED CO-ACTION IN DEVELOPING POSSIBILITIES IN PRODUCT

© LE Co. 1954



JETWELDS COST-CUTTING TEAM SPEEDS WELDING 35% AND MORE

FOR THE FIRST TIME, Lincoln Jetweld joins powdered metal with the electrode to achieve fastest hand welding speeds ever accomplished. Jetweld's phenomenal speed lies in utilizing the maximum heat of the arc for melting the parent metal, core wire and coating.

GET JETWELD'S COST-CUTTING FACTS TODAY... Have your Lincoln welding engineer demonstrate Jetweld's many cost saving features. Or write for free Bulletin 481.

JETWELD-2 (E-6020)

Extra fast electrode for flat, deep grooves and flat and horizontal fillets.

Tensile strength (As welded) 62,000 psi minimum

Yield strength (As welded) 52,000 psi minimum

Elongation in 2" (As welded) 25% minimum

JETWELD-1 (E-7020)

Extra fast electrode for flat and horizontal fillets.

Tensile strength (Stress relieved) 80,000—90,000 psi

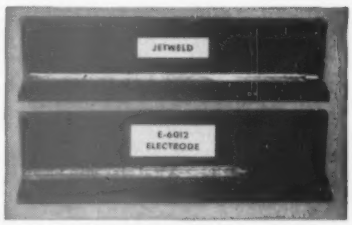
Yield strength (Stress relieved) 65,000—75,000 psi

Elongation in 2" (Stress relieved) 25%—30%

Jetweld electrodes have been tested and approved by the American Bureau of Shipping and are certified to conform to AWS classes E-7020 (Jetweld 1) and E-6020 (Jetweld 2).

This certification authorizes the use of these two electrodes in shipbuilding supervised by the American Bureau of Shipping and the U. S. Coast Guard.

BENEFIT THREE WAYS WITH LINCOLN JETWELD



35% AND FASTER welding speeds are possible with the new Lincoln Jetweld electrodes. That's because powdered metal coatings utilize the heat of the arc more efficiently to increase welding speeds. Iron powder, melted by excess heat available in the arc, becomes an additional source of metal for the weld.

HIGHER QUALITY Weld metal is uniform, of X-ray quality, free of undercut with improved impact values at low temperatures. There is no coating breakdown . . . stub losses are less. Bead appearance is smooth . . . looks like an automatic weld.

LESS CLEANING is required with Jetweld. Heavy coating and short arc prevent spatter. Slag is self-cleaning. Excellent "wash-up" eliminates undercutting and entrapped slag.

THE LINCOLN ELECTRIC COMPANY

Dept. 1903

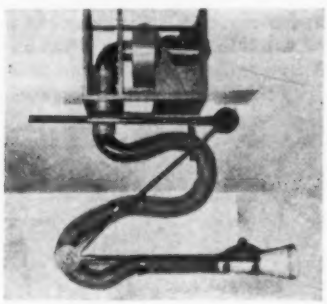
CLEVELAND 17, OHIO

THE WORLD'S LARGEST MANUFACTURER OF ARC WELDING EQUIPMENT

NEW PRODUCTS

Welding Fume Exhauster

The Engwald Corp., 357 Lafayette Ave., Brooklyn 38, N. Y., has just introduced their No. W-200-9 Welding Fume Exhauster which is being incorporated in installations where elimination of electric-arc or gas-welding fumes is desirable. According to the manufacturer, these and other fumes present a serious hazard to the welder, mechanic or anyone working in the shop. The unit is highly efficient because the fumes are collected at the source



by an adjustable cone hood which is connected to the exhaust hose. All fumes are drawn into the large cone opening before they can circulate. The W-200-9 comes with a heavy-duty pressure blower. The unit works in a radius of 360 deg if mounted on the coiling or 180 deg if mounted on the wall. Arm and hose assembly can be supplied in various lengths to suit any requirement. It is also available in portable or standing floor units. Complete descriptive literature is available by writing the manufacturer.

Soldering Tool

Operating voltage at tip only 3½ to 12½ v. No danger of shock. No heat generated except when in contact with work. Completely enclosed transformer protected with easily replaceable 4-amp fuse.

Light in weight. Reaches into smallest corners. Twin carbon electrodes establish instant soldering contact at right spot. No separate connection to work needed.

Work heated instantly to soldering temperature. Solder flows on smoothly and evenly. Choice of six soldering heats gives maximum efficiency.

Long-life carbons last months in steady use. Changed quickly and economically. Very low current consumption.

Transformer operating voltage is 110–120 v, ac, 60 cycles.

Solder-Quiks are in use today in radio and television shops, typewriter service departments, electric motor repair shops and others.

Stark Manufacturing Co., P.O. Box 489, Tuscaloosa, Alabama.

"Recap" Tips and Adapter Shanks

The Resistance Welding Division of Ampco Metal, Inc., announces the new addition of "Recap" Tips and Adapter Shanks to the product lines of Ampco-Weld for immediate off-the-shelf delivery.

In addition to providing a double water seal and being made out of high-quality, high-conductivity alloys, the advantages of this new product are as follows:

1. The welding face of the tip can easily be ejected without removing the entire electrode from the holder.
2. Electrode dressing cost and down-time on equipment is saved in high production shops.
3. Because of its taper length, the insert can be used in dies and in many restricted places where clearances are inadequate to permit a standard tip.

For further information regarding this new product announcement, please contact Ampco Metal, Inc., 1745 S. 38 St., Milwaukee, Wis.

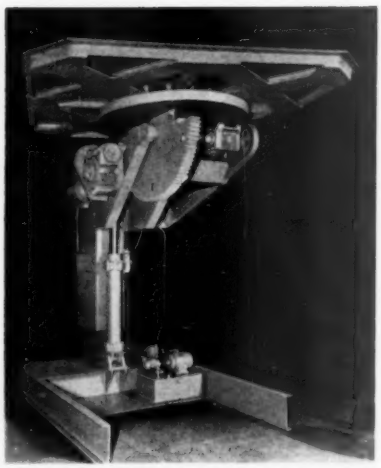
Heavy Weldments Positioned

The major problems confronting manufacturers of weldment positioners, especially under heavy loads, are:

1. Where to absorb the large torques that are developed.
2. How to efficiently prevent "drifting" of the positioner table under these heavy loads.
3. Positioning the load smoothly, continuously and accurately.

Pandjiris Weldment Co., St. Louis, answered these problems simply and economically by using double-enveloping worm gear speed reducers, manufactured by Cone-Drive Gears, Division Michigan Tool Co., Detroit, to drive their positioners.

Typical of their complete line of Pandjiris "Weldmore" welding positioners is the 40,000-lb unit illustrated. The three-way movement of the positioner table locates work for down-position welding



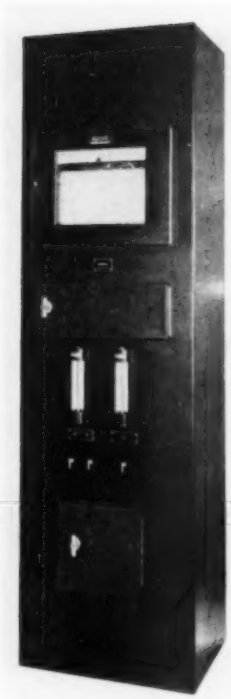
either for hand, semiautomatic or full-automatic welding. Any load placed on the positioner table is absorbed as torque at the output shaft of the speed reducers. A 70:1, 10-in. center distance standard speed reducer, which must absorb torques up to 150,000 in.-lb drives the tilting system. Another 70:1, 7-in. center distance standard speed reducer, which must absorb torques up to 52,000 in.-lb, drives the rotating system. The table may be tilted in an arc of 135 deg and rotated a full 360 deg. In addition, it can be elevated vertically up to 4 ft through a built-in hydraulic lift system.

Argon Purity Analyzer

An instrument to measure the purity of argon gas has been developed by the Thermco Laboratories, Johnson Road, Michigan City, Ind. Accurate to 0.01%, this new instrument was designed to continuously analyze production processes in the manufacture of welding grade argon—which must have a purity content of not less than 99.92%. The Analyzer is normally supplied with two scales. For normal operating, a range of 99–100% argon is used to measure the purity of the finished product supplied to the cylinder banks. An auxiliary range of 80–100% argon is supplied to measure the crude argon—or while starting up the purifying column. Laboratory tests by independent research organizations have verified the continuous accuracy maintained by the units now in operation at argon-producing plants.

Compact and self-contained, the unit is ready for operation after making the proper current and sample connections.

FLOWLINE®
WELDING FITTINGS
Stainless Steels · Monel · Nickel · Aluminum
4027 stock items
You can plan for economical, efficient butt-welded corrosion piping with assurance of quick availability of FLOWLINE Fittings. Delivery can be made from stock by leading distributors. Made in sizes ½" through 12" — Schedules 5S, 10S, 40S, 80S — Stainless Types 304, 304L, 316, 347; Monel, Nickel, Aluminum. Seamless fittings with all the plus values . . . at no extra cost.
WELDING FITTINGS CORP.
NEW CASTLE, PENNSYLVANIA
World's Largest Manufacturer of Stainless Welding Fittings
Remember FLOWLINE WELDING FITTINGS
Forget CORROSION PIPING PROBLEMS



Argon Purity Recorder

Assembled as a complete unit on a panel cubicle the instrument operates by comparing the thermo conductivity of a sample with a known standard. Measuring cells are easily interchangeable, so that in event of failure, a spare cell can be quickly placed in operation.

For further details contact Robert D. Richardson, Director of Engineering, Thermco Laboratories, Johnson Road, Michigan City, Ind.

Table Lift

A portable table lift with a flat steel swivel top was introduced this month by West Bend Equipment Corp. to handle heavy jigs and dies weighing up to 2000 lb.

Mounted on large ball-bearing wheels and raised hydraulically with a foot pump, the Weld-Bilt unit also serves as a sheet or strip feeding table, an easily moved portable elevator for loading trucks, storing tools and dies or as a temporary work bench.

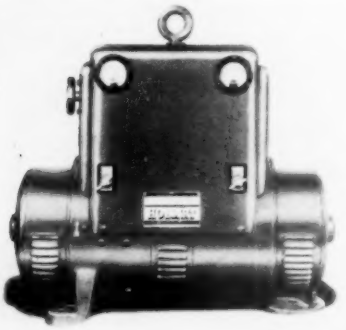
Simply operated, the rugged portable table has a lift of from 28 up to 42 in. and maximum capacity of 2000 lb.

Further information is available from West Bend Equipment Corp., 349 Water St., West Bend, Wis.

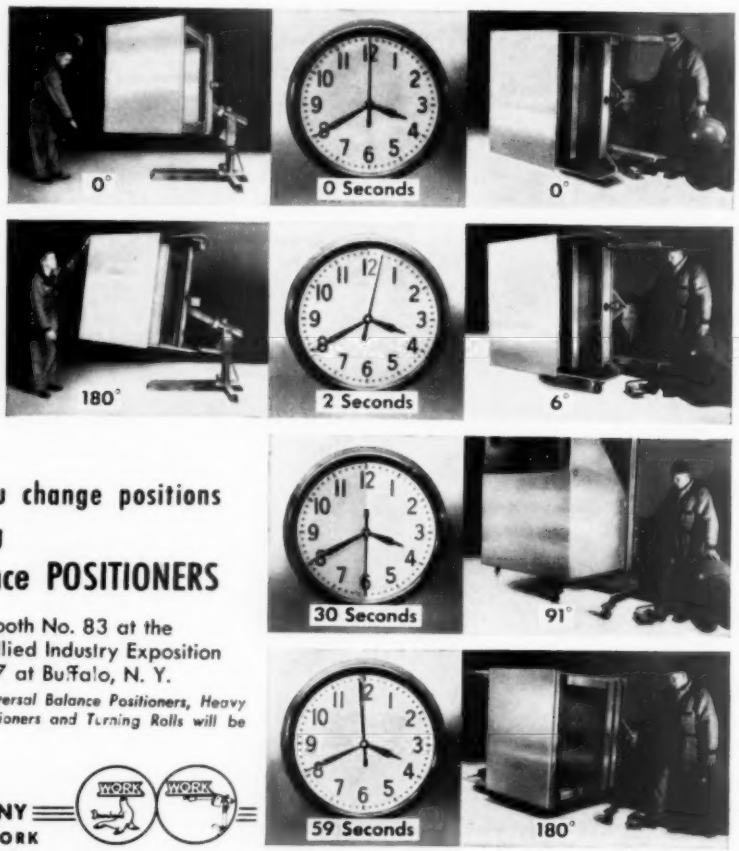
Constant Voltage D-C Arc Welder

A new constant voltage type d-c arc welder especially designed for welding with inert-gas-shielded arc, the submerged arc and other automatic processes is being announced by Hobart Brothers Co., Troy, Ohio.

The convenient hand wheel on the side of the control cabinet lets the operator set



Aronson
UNIVERSAL BALANCE POSITIONING
Versus
POWER GEAR DRIVEN POSITIONING



YOU SAVE A NICKEL everytime you change positions if you are using
Aronson Universal Balance POSITIONERS

"Downhand" says:

Visit our Booth No. 83 at the Welding and Allied Industry Exposition May 5 to 7 at Buffalo, N. Y.

A complete line of Universal Balance Positioners, Heavy Duty Gear Driven Positioners and Turning Rolls will be demonstrated.

Aronson MACHINE COMPANY
ARCADE, NEW YORK

Top D.C. PERFORMANCE miller SR WELDERS

- time tested-proven features
- all the features you wanted

4 MODELS

When it's... miller ...you know there's none better!

HEAVY DUTY CONTINUOUS

Production A.C. WELDING miller 100 SERIES

6 MODELS

Write Why not get the complete story on MILLER welders — whether D.C. or A.C. — TODAY? See your MILLER distributor.

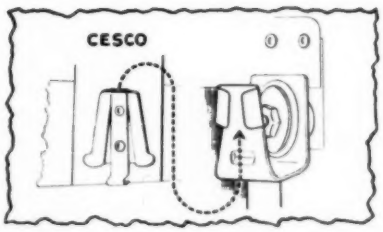
MILLER ELECTRIC MANUFACTURING CO.
SINCE 1929 • APPLETON · WISCONSIN

the machine for the desired arc voltage, which remains constant regardless of the amount of current being used. This is made possible by Hobart's separately excited design with sufficient compounding, providing a very high short-circuit current value. As soon as the welding wire strikes the work, a surge of current practically vaporizes the wire and establishes an arc immediately. Enough current then flows to cause the arc voltage to correspond to the preset generator voltage. When used with a process wherein the wire is fed continuously into the weld, the machine automatically controls the current by maintaining the voltage at the established value regardless of changes in the speed at which the wire is fed to the arc. Excellent results will be obtained with this equipment on any desired voltage setting—from 20 to 40 v.

Available in 3 rated capacities of 400-, 600- and 900-amp for operation on electric power supply of 2- or 3-phase, 60 cycles, 220/440 v (dual) or for 550 v (single). For complete information write Hobart Brothers Co., Troy, Ohio.

Head and Eye Protection

A new way to save money on the purchase of head, face and eye protection equipment has just been announced by the

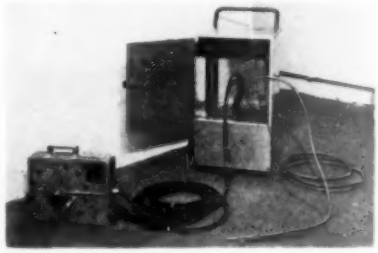


Chicago Eye Shield Co., makers of CESCO safety equipment. It consists of combinations of a head gear and helmet, or plastic shield, or wire-screen shield; or hard hat with the same protective equipment.

The basis for making these combinations is the new CESCO mounting device. It consists of wedge-shaped brackets which slide together and lock securely, and which may be as quickly unlocked. A tilting mechanism allows the user to raise or lower the helmet or shield without difficulty, and an easily adjusted tension spring compensates for the difference in weight of the different pieces.

With five pieces of CESCO equipment consisting of a head gear, hard hat, welding helmet, plastic shield and a screen shield, it is possible to make six combinations which formerly required 12 items, the duplication combining in the head gears and hard hats.

Further information on this new CESCO mounting may be obtained by writing to Chicago Eye Shield Co., 2300 W. Warren Blvd., Chicago.



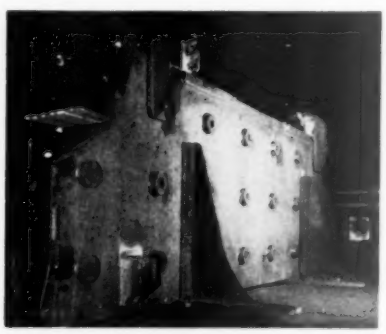
Cobalt 60 Radiographic Equipment

Technical Operations, Inc., 6 Schouler Court, Arlington, Mass., announces the design and production of the PES (Panoramic Exposure Shield) for use in Cobalt 60 radiography. The PES was developed to permit the safe handling of strong radioactive sources for three specific requirements: exposures in internal locations, often otherwise impossible or extremely difficult to make; radiography where electric power is not available; panoramic exposures.

MANGANAL
U.S. Patents 1,876,738 - 1,947,167 - 2,021,945
11%-13½% Manganese-Nickel Steel
APPLICATOR BARS
and
WELDING ELECTRODES
Rebuild Worn
HAMMERMILL HAMMERS
Quickly and Easily!
It's the NICKEL in MANGANAL that makes welding and fabricating easier; and it's the MANGANAL Applicator Bars that allow you to rebuild Hammermill Hammers quickly because you minimize build-up time.
"HOW TO DO IT" DETAILS SENT ON REQUEST
Mill Depot Stocks: Newark • Wilkes-Barre (Forty Fort) • Indianapolis • Minneapolis
STULZ-SICKLES CO.
NEAREST DISTRIBUTOR UPON REQUEST
SOLE PRODUCERS 92 N. J. RAILROAD AVE. NEWARK, N. J.

Forging Supports

Attachment of pads to crosshead support forgings was one of the Bethlehem Steel Co. weldment jobs in fabricating parts for a 35,000-ton die forging press, a unit in the Air Force heavy press program. The press, designed by Loewy-Hydropress, Inc., will be erected at North Grafton, Mass.



Weighing 95 tons, the crosshead support is 47 ft long at the base and stands 14 ft high, at the Bethlehem, Pa., plant of Bethlehem. Besides the pads and bracket at lower left, 22 bosses were welded to each side of the support. The bosses, which were cut out of rolled plate 5 in. thick, have an inside diameter of 6 in. and an out-

side diameter of 15 in. In the press, they will receive bolts 14 ft long which will hold together 10 of the supports as a rigid backing for a set of forging dies.

Welding Goggle

The new Model 492 SV "Stac-Vent" Goggle for welding combines greater comfort with lower cost protection. "Stac-Vent," a new principle of goggle ventilation, prevents fogging . . . provides draft ventilation at the top and center of the goggle where warm, moist air normally accumulates. Large openings for ventilation are safely shielded by the "Stac-Vent" hood. The opaque black soft vinyl plastic frame, large enough to fit over all prescription glasses, comfortably form-fits the contours of the face and nose, leaving no gaps. A heavy, opaque lens holder has lens pockets for replaceable 50-

mm round, Federal Specification, glass filter lenses, protected both inside and outside by hard plastic cover lenses. The inside cover lens eliminates the danger of glass splinters reaching the eye, if impact should break the filter lens. Outside cover lens is easily replaced without removing filter lens or inside cover lens. Goggles can be furnished with filter lenses in shades Nos. 3, 4, 5, or 6.

Manufactured by Watchemoket Optical Co., 232 W. Exchange St., Providence, R. I.

Fluorescent Penetrant Inspection

A new scale of sensitivity in penetrant inspection is available in new fluorescent penetrant inspection materials, to be introduced by Magnaflux Corp. at this year's ASTE Tool Show. Named Zyglo-Pentrex, the new penetrant has been used in a long series of controlled field trials under its experimental name, PE or postemulsification. Its first pilot use in volume was in the important inspection of gas turbine buckets.

New Zyglo-Pentrex has its greatest advantage over previous penetrant inspection methods in finding both very tight cracks and broad, shallow defects. Other fluorescent penetrants will generally miss these extreme types of defects. Thus, Zyglo-Pentrex widens the area of use for penetrant inspection at both extremes. This seems even more paradoxical when it is explained that the reason for increased sensitivity is the same in both cases.

Zyglo-Pentrex contains no emulsifier. The emulsifier is added to the part after penetration by a separate dip. In this way, both emulsification time and washing are controlled to suit the particular part or type of defect.

Acetogen Gas

Acetogen gas for precision metal cutting, brazing and silver soldering has been made available in New York City, Connecticut and surrounding areas by the Acetogen Cutting Gas Co., Inc. Acetogen gas provides fast preheating times, produces smooth cuts with sharp edges, causes no appreciable hardening of cut surfaces and leaves no adhering slag.

Acetogen gas is especially suitable for brazing and silver-soldering operations because the characteristics of the flame enable uniform heating of large areas of metal with no tendency for melting, burning or change of temper.

Acetogen gas, one cylinder of which is equivalent to four cylinders of acetylene, makes possible a more economical operation due to lower cost of gas consumed and savings in cylinder handling.

The use of Acetogen gas will not blow back, blow out or explode. The gas burns with a nonincandescent flame, is nontoxic and produces no soot or carbon deposits.

Information concerning this product may be obtained by writing to Acetogen Cutting Gas Co., Inc., at 26 Court St., Brooklyn 1, N. Y.

All-Purpose Flux

A new, exclusive, all-purpose welding and brazing Andco Uni-Flux has just been announced by Andco, Inc., Orchard Park, N. Y.

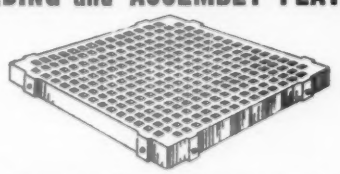
This new, revolutionary flux, developed by years of research, testing and application, provides one flux for all types of gas welding and brazing. This eliminates inventories up to a dozen different fluxes, as well as the use of wrong fluxes and rods by inexperienced welders.

Andco Uni-Flux welds through lead, beryllium, aluminum, bronze, galvanize, copper, rust, grease, paint, tar and dirt. It also brazes and welds cast iron, chrome metals, stainless, monel, aluminum, bronze, silver solder and many other alloys. No cleaning is required. It cleans as it is used during welding and brazing operations.

Andco Uni-Flux eliminates impregnation of foreign substances into the metal surface and also eliminates crystallizing of metal. To overcome these conditions it produces an inert atmosphere around the weld area that keeps oxygen away from

Buy "PROVEN FLUXES"
Years of GUARANTEED SATISFACTION
behind these GOOD
"ANTI-BORAX" FLUXES
Insist on them — Unequalled Quality
No. 1 Cast Iron Welding Flux
No. 2 Brazing Flux for Brass, Bronze, Steel, etc.
No. 4 Braz-Cast Flux for Bronze Welding Cast Iron
No. 5 & 8 Cast & Sheet Aluminum Fluxes
No. 9 Stainless Steel Welding Flux
No. 11 Tinning Compound
No. 16 Silver Solder Paste Flux
Mfg. By
ANTI-BORAX COMPOUND CO., INC.
Fort Wayne, Ind.

WELDING and ASSEMBLY PLATENS



Floor plates — bending tables — layout tables — straightening tables — dog blocks — bending blocks — blacksmith blocks. 5′x5′ — 6′x6′ — 6′x8′ — 6′x10′ — 5′x10′ — 6′x12′ — 3′x3′ — either 6″ or 7″ thick.
STAHL EQUIPMENT CO.
94 Washington St., Brookline Village 46, Mass.

Weld it once and done
no cracks, no porosity

Lightweight, tough, high tensile steels have made it possible for truckers to haul heavier loads with less dead weight—a decided economy.

No less important in saving time and money is the use of low hydrogen electrodes to weld these steels. When you weld low alloy high tensile steels—whether your requirements are tough or easy—Arcos Low Hydrogen Electrodes will consistently produce sound welds . . . welds that are free of cracks or porosity. There is no reworking of such welds—no chipping or re-welding to add more time to the job. The ability of Arcos weld metal to stand up in tough service—such as the strain on truck bodies of heavy loads or the impact of sudden stops and starts—is the result of high standard quality controls in the manufacture of Arcos electrodes.

Send for the free Arcos booklet, "The ABC's of Welding High Tensile Steels". Arcos Corp., 1500 South 50th Street, Philadelphia 43, Penna.

ARCOS GRADE	A. W. S. SPEC.
Tensilend 70	E7016
Tensilend 100	E10016
Tensilend 120	E12015
Manganend 1M	E9015
Manganend 2M	E10015
Nickend 2	E8015
Chromend 1M	E8015
Chromend 2M	E9015

WELD WITH ARCOS
LOW HYDROGEN ELECTRODES

such foreign substances as dirt, grease, rust, paint and metal finishes by prohibiting the burning of these substances. Instead, the foreign substances harmlessly float away with the wetting action of the melted flux, leaving no carbon or other types of deposit.

Andeo Uni-Flux will not spoil, even over exceptionally long periods of time.

For complete information on this new Andeo Uni-Flux, write: Andeo, Inc., 235 Thorne Ave., Orchard Park, N. Y.

Aircraft Welder

Where exceptional remote control is desirable, here is a new Selenium rectifier type d-c arc welder introduced by Miller Electric Manufacturing Co., Appleton, Wis., under the name "Aircrafter." While it was originally brought on the market in response to demand from the aircraft industry it has been received enthusiastically by metal fabricators who have need

for its special features. The "Aircrafter" is made with extreme current ranges . . . a remote foot switch controls an extreme current range 5 to 95 or 12 to 180 or 55 to 300 depending upon range selector switch setting, and shuts off the welder when the minimum output is reached. One of the specific requirements of this new welder was to eliminate craters and to permit a metallurgical refining action to occur at the end of the weld bead. With its welding current arrangement the operator may hold the torch over the weld puddle and by varying the welding current he can fill in the crater and control the cooling rate of the weld deposit.

The "aircrafter" is supplied complete with primary contactor, control transformer and remote foot control with microswitch. In addition to its exceptional remote control features it has remarkable arc flexibility, rectifiers used in its manufacture are specifically designed for welding applications, "unitized" dual current control, instantaneous polarity selection, rugged rectangular drip-proof cabinet. Any number of these welders can readily be paralleled to produce greater output.

Regulators Made of Forged Aluminum

A complete line of new pressure regulators for use with most compressed gases is announced by the K-G Equipment Co. (Inc.), 1744 Lehigh St., Allentown, Pa. The two-stage models are designated 1100 Series, and the single-stage models, 1200 Series.

Both series afford excellent pressure regulation and a low end point. Each includes many models, for use with oxygen, fuel gases and inert gases over a wide range of pressure and volume requirements.

The new regulators feature forged, heat-treated, anodized aluminum alloy construction for light weight, compactness and ruggedness. Bodies, bonnets and spring cases are made of this material.

Another new feature is the 4000-lb high-pressure gage, suitable for today's higher cylinder pressure, that is supplied on all models except the fuel gas regulators. These are equipped with a 500-lb high-pressure gage.

Dual-Head Resistance Welder

A dual-head resistance seam welding machine which maintains complete setups for either longitudinal or circular seam welding is announced by the Universal Welder Corp., 2557 E. 79th St., Cleveland 4, Ohio.

Mounting two heads at 90 deg, the new unit can be switched from circumferential to straight-line work at the flick of a switch.

The new welder eliminates approximately two man-hours of downtime normally required to change over a conventional Universal machine from one class of work to the other. This saving effects substantial economies where changeovers are frequent, or where a product requires both types of seam welding concurrently at assembly.

Available in a size range of from 30 to

When you want to ***lick corrosion*** *for longer equipment life*

Getting good corrosion resistance starts with a base metal of desirable characteristics. However, maximum equipment life can be assured only when the welds possess the same corrosion resistance as the base metal.

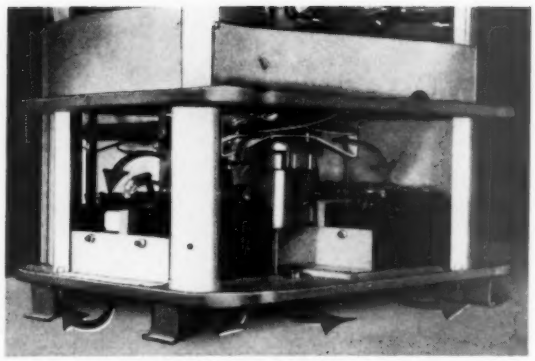
ARCOS STAINLESS ELECTRODES are designed to deliver the results you need on *all* your welding jobs. Regardless of the requirements, there's a wide selection to provide the best suited electrode for every application. Because each is backed by Arcos quality controls, you have complete assurance of physically, chemically, and metallurgically sound weld metal. That means longer-lasting welds . . . less time and fewer dollars for maintenance. Write for your free copy of "What Electrode Would You Use?"

Arcos Corporation, 1500 South 50th St.
Philadelphia 43, Pennsylvania

WELD WITH ARCOS STAINLESS ELECTRODES

WELDING ARCS NEWS

SINGLE-SCALE, DUAL-RANGE current indicator makes it easy to set and check current. Safety cover over terminals can be lifted by hand, is self-closing. Welder can be supplied either for 2-phase or 3-phase power supply.



REVERSIBLE VENTILATING FAN above rectifier stacks of unit is used to blow dust from rectifiers and transformer to prolong rectifier life.

FULL-TIME ARC FORCE CONTROL is turned on by toggle switch. It effectively minimizes stubbing and freezing-in on tough jobs at high speed.

Announcing — the first of a new line of powerful G-E rectifier welders

New 400-amp General Electric rectifier set includes new features for longer life and improved performance

Now, before you buy any d-c welder, be sure to try the 400-amp General Electric rectifier welder—first of a new line to be introduced this year.

Here's a d-c welder that lives up to the General Electric reputation for long-life dependability. And it's a full-fledged 400-amp unit, fully capable of short-time 500-amp output.

CHECK THESE G-E ENGINEERED USER BENEFITS

Easy Operation—instant starts plus easy, precise current-control please operators, improve work.

High Production—stable arc permits higher speeds; quiet operation reduces fatigue, boosts output.

Long Life—due to lack of moving parts (except fan), silicone insulation, advanced-design ventilation.

Low Operating Costs—high efficiency and low idle-time power consumption cut power bills; easy-access design speeds inspection and maintenance.

TWO EXCLUSIVE MONEY-SAVING FEATURES

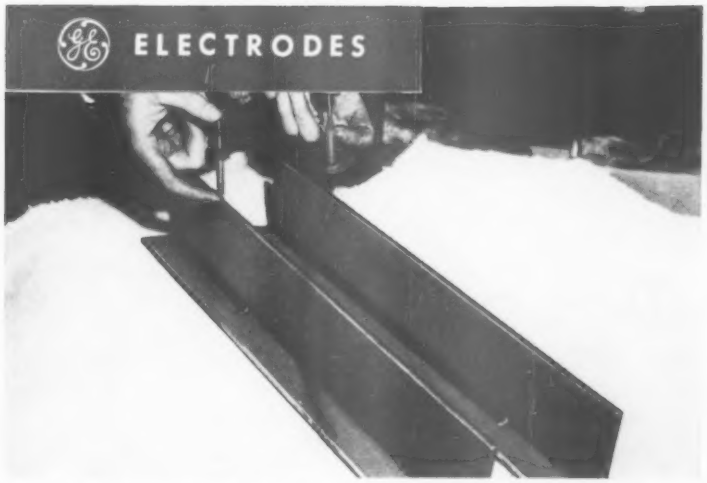
These exclusive features solve user problems:

Reverse-draft Fan—the powerful ventilating fan can be reversed to blow dirt off rectifiers and transformers. This cleaning action minimizes a major cause of rectifier failure.

Full-time Arc Force Control—available as optional equipment—lets you hold a short arc on those extra-tough welding jobs with little chance for popouts or freezing-in.

CONTACT YOUR G-E DISTRIBUTOR TODAY!

For full data on the new G-E 400-amp rectifier welder, contact your G-E Welding Distributor today. He's listed here and in the yellow pages of your phone book under "Welding Equipment—General Electric." General Electric Co., Schenectady 5, N. Y. 710-16



SEE THE DIFFERENCE! New G-E contact electrode produced 19" of fillet in 88 sec. E-6020 rod produced an 8" of fillet in 75 sec. Both tests used 3/16" electrodes on 1/4" mild steel using 230 amps DC.

New G-E Strikeasy 1 electrode for high-speed contact welding

Actual comparison tests indicate that G.E.'s new Strikeasy 1 contact-type electrode produces significantly more weld footage in a given time than high-quality E-6012 and E-6020 electrodes. This high speed can save you as much as 35% in total welding costs.

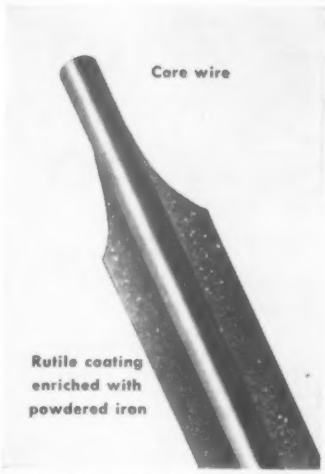
The new Strikeasy 1 electrode has a rutile coating enriched with powdered iron. This iron melts to form part of the weld bead, greatly increasing the rate of metal deposit. The new G-E electrode operates on AC or DC and is available in 1/8", 5/32", 3/16", 7/32", and 1/4" sizes.

WIDELY APPLICABLE

The Strikeasy 1 electrode is for certain mild-steel and low-alloy welding where you would normally consider an E-6012 or E-6020 rod. Typical uses include low-pressure storage tanks, machine bases, and light structural work.

OTHER PERFORMANCE BENEFITS

- **Less Spatter**—as much as 80% less, a real saving in material.
- **Self-cleaning**—no need to hammer and chisel to remove scale.
- **Easy-to-use**—operates smoothly, minimizes d-c arc blow, reduces operator fatigue.



POWDERED IRON in coating of new G-E Strikeasy 1 electrode increases metal deposit rate.

Contact your nearby G-E Welding Distributor today for samples of the Strikeasy 1 electrode.

You'll Find the Best Electrode for Your Job in the G-E Line—Most Complete in the Industry

G-E WELDING DISTRIBUTORS

Alabama: Birmingham—Alabama Oxygen, Young & Vann Supply; Mobile—Turner Supply

Arizona: Phoenix—Consolidated Welding Supply

California: Fresno, Los Angeles, Oakland, Sacramento, San Diego, San Francisco, Ventura—Victor Equipment

Colorado: Boulder, Colorado Springs, Denver, Durango, Ft. Collins, Ft. Morgan, Greeley, LaJunta, Longmont, Pueblo, Sterling—Hendrie & Bolthoff

Connecticut: Hartford, New Haven—Harris Sales & Service

Florida: Hollywood—Florida Gas & Chemical

Georgia: Atlanta, Macon—Welding Supply & Service; Augusta—Marks Oxygen; Columbus—Williams Welding Supplies

Idaho: Boise—Olson Manufacturing

Illinois: Chicago, Moline, Morton, Rockford—Machinery & Welder

Indiana: Evansville—Drillmaster Supply; Ft. Wayne, Indianapolis—Sutton-Garten; South Bend—Perry Welding Sales & Service

Iowa: Des Moines—Machinery & Welder

Kansas: Hutchinson—Kopper Supply

Kentucky: Louisville—Reliable Welding; Paducah—Henry A. Petter Supply

Louisiana: Alexandria, Shreveport—Hughes Oxygen; New Orleans—Consolidated Welding Supplies

Maryland: Baltimore—Arcway Equipment

Massachusetts: Boston—New England G-E Welding Sales Division

Michigan: Detroit—Welding Sales & Engineering; Grand Rapids—Miller Welding Supply

Minnesota: Duluth—W.P.&R.S. Mars; St. Paul—Production Materials

Mississippi: Jackson—Jackson Welding & Supply

Missouri: Kansas City—Hohenschild Welders Supply; St. Louis—Machinery & Welder

Montana: Billings—Valley Welders Supply; Billings, Bozeman, Cut Bank, Glasgow, Great Falls, Havre, Kalispell, Miles City, Shelby, Sidney, Whitefish—Valley Motor Supply; Butte, Great Falls—Montana Hardware

Nebraska: Lincoln—Lincoln Welding & Supply; Omaha—Baum Iron

New Jersey: Kenilworth—Welding Sales Corp.

New Mexico: Albuquerque—Industrial Supply Co. Hobbs—Western Oxygen; Las Cruces, Silver City—Car Parts Depot, Inc.

New York: Buffalo—Welding Equipment Sales; New York—Welding Sales Corp.; Syracuse—Welding Engineering & Equip.

North Carolina: Charlotte—Dixie Gases; Gastonia—Gastonia Motor Parts

North Dakota: Bismarck, Fargo—Acme Welding Supply

Ohio: Akron, Cincinnati, Cleveland, Columbus, Dayton, Mansfield—Burdett Oxygen; Toledo—Odland Iron Works

Oklahoma: Tulsa—G-E Welding Sales Division

Oregon: Eugene, Portland—J. E. Haseltine; Medford, Portland—Industrial Air Products

Pennsylvania: Allentown, Philadelphia, Pittsburgh—Arcway Equipment

South Carolina: Columbia, Greenville—Welding Gas Products

South Dakota: Deadwood—Hendrie & Bolthoff

Tennessee: Chattanooga, Knoxville, Nashville—Welding Gas Products; Memphis—Delta Oxygen

Texas: Abilene—M&M Welding Supply; Alice, Corpus Christi—Crane Welding Supply; Alpine, El Paso, Marfa, Pecos—Car Parts Depot; Amarillo—Welding Equipment & Supply; Beaumont—Beaumont oxygen; Brownsville, Harlingen—Acetylene Oxygen; Dallas—Hill Equipment & Supply; Houston—G-E Welding Sales Division; Lubbock—Welders Supply of Lubbock; Midland—West Texas Welders Supply; Odessa, Pecos—Western Oxygen; Orange—Marine & Petroleum Supply; Pecos—Welding Supply Co.; Plainview—Plains Welding Supply; San Angelo—Southwestern Welding Supply; Texarkana—Hughes Oxygen; Wichita Falls—Nortex Welding Supply

Utah: Salt Lake City—The Galigher Co.

Washington: Seattle, Spokane—J. E. Haseltine; Spokane, Yakima—Industrial Air Products

West Virginia: Bluefield—Bluefield Supply; Charleston—Virginian Electric; Huntington, Logan—Logan Hardware & Supply

Wisconsin: Milwaukee—Machinery & Welder

Alaska: Anchorage—Northern Supply

Canada: Toronto—Canadian G.E.

Hawaii: Honolulu—American Factors, Ltd.

GENERAL ELECTRIC

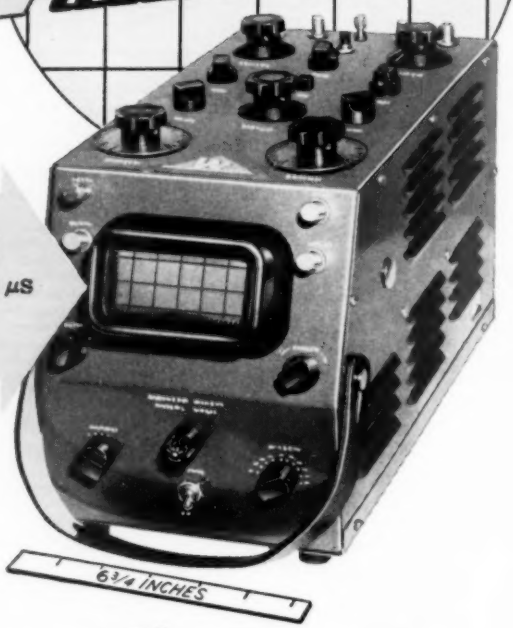
BROAD BAND PULSESCOPE

by Waterman

MODEL S-6-A

DC CALIBRATION MARKERS 1-1000 μs 0-5 mc

Size:
8½" x 6¾" x 13¾"
22 Pounds



ANOTHER EXAMPLE OF Waterman PIONEERING...

The S-6-A BROAD BAND Scope is a PULSESCOPE in performance, POCKETSCOPE in size, and it compares more than favorably with oscilloscopes that are *transportable*, instead of portable. The instrument measures DC as well as AC signals. Unique DC calibration methods permit rapid measurements of either positive or negative AC or DC signals. The scope uses a 3XP1 tube with 1500 volts on the second anode, thus providing a brilliant trace for high speed transients even at low repetition rates. Vertical amplifier sensitivity of 0.2v rms/inch, and response to 5 mc within 3DB . . . pulse rise time of 0.1 μs . . . internal intensity markers from 1 to 1000 μs . . . repetitive or trigger sweep from 5 cycles to 500 KC with 5X sweep expansion . . . sweep, marker and DC calibrating voltage available externally. Size 8½ x 6¾ x 13¾ in. Weight 22 lbs. Operates from 50 to 400 cycles at 115 volts AC.

WATERMAN PRODUCTS CO., INC.

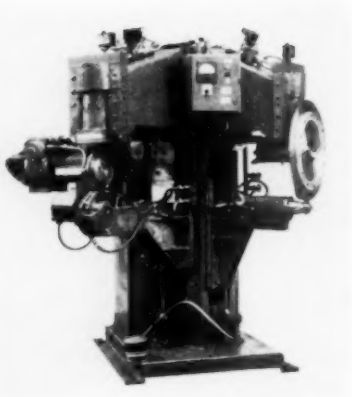
PHILADELPHIA 25, PA.
CABLE ADDRESS: POKETSCOPE

MEMO .. Write for details today!

WATERMAN PRODUCTS

WATERMAN PRODUCTS INCLUDE

S-4-C SAR PULSESCOPE®
S-5-A LAB PULSESCOPE
S-6-A BROADBAND PULSESCOPE
S-11-A INDUSTRIAL POCKETSCOPE®
S-12-B JANized RAKSCOPE®
S-14-A HIGH GAIN POCKETSCOPE
S-14-B WIDE BAND POCKETSCOPE
S-15-A TWIN TUBE POCKETSCOPE
RAYONIC® Cathode Ray Tubes and Other Associated Equipment



Dual-Head Resistance Welder

150 kva, the dual-head machine operates on 440- or 220-v, 60-cycle, single-phase power. Either head operates from a single transformer, but both have individual drives with variable speed control as well as separate heat controls.

Conventional wheel arrangements or any one of a wide variety of special wheel setups are accommodated by the machine. While the standard unit is supplied for continuous longitudinal seam welding, the new machine is also available equipped for roll spot-welding work.

New Plastic Welding Helmet

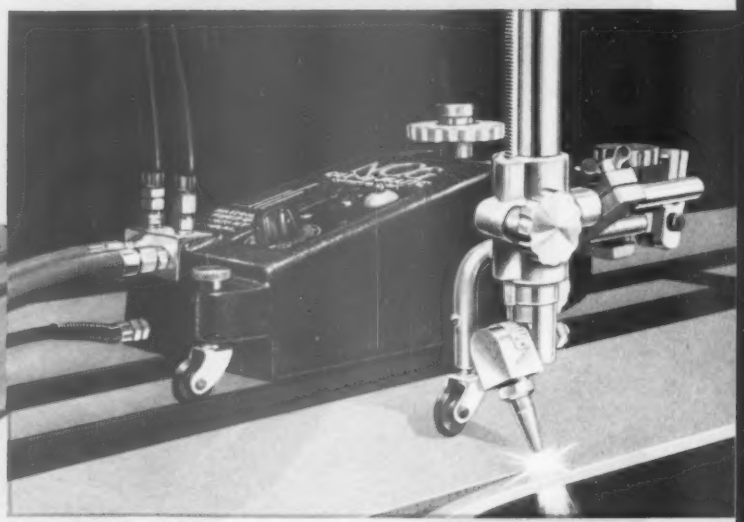
Both safety and comfort are provided for welders by a new seamless plastic welding helmet announced by the General Electric Co.'s Welding Department.

Lightweight and strong, the new helmet incorporates G-E standard ventilation design for cooler welding and prevention of lens fogging. The plastic shell is heat-resistant, moistureproof and nonwarping, according to company engineers.

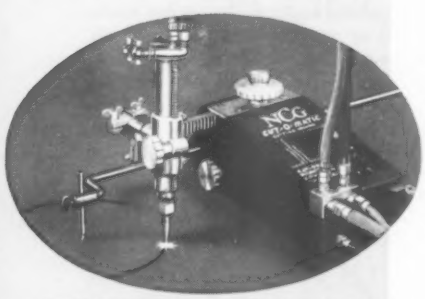
The headgear is designed to fit the contour of any head. Wider range head-size adjustment is provided by a ratchet-type device and a four-position stop meets vertical and overhead needs.

The helmet is available in a durable black finish with or without a flip-front. Respective weights of the two models are 29 and 25 oz.

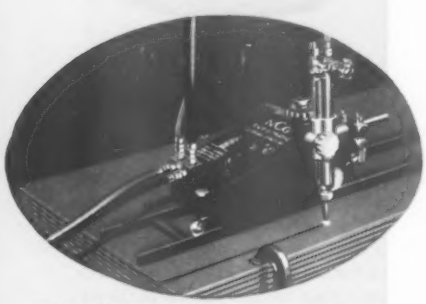
to increase Cut-O-Matic's® Versatility



Cut-O-Matic is NCG's low-cost portable flame-cutting machine. Motor driven. Runs on own tracks. Weighs only 50 lbs. Can be carried anywhere. Saves time and gas.



Cut-O-Matic cuts steel plates, sheets, heavy slabs. Cuts on square or bevel, straights, strips, circles, rings and arcs.



Stack cutting. Sheets can be clamped together, and cut all at once, giving real production and economy.

NEW FLOATING TORCH ASSEMBLY...

cuts Smooth Bevels on Wavy Plate

The usefulness and versatility of Cut-O-Matic that have placed this low-cost, portable flame-cutting machine in so many shops, are now broadened greatly with the introduction of the Floating Torch Assembly. This NCG development automatically results in smooth, accurate bevels on wavy or bulging plate surfaces. The contour wheel raises or lowers the swivel-head beveling torch to compensate for surface unevenness, holding torch tip at same angle and distance from plate.

This is only one of many superiorities that make Cut-O-Matic so profitable, productive and economical. You can have the versatile Cut-O-Matic and the Floating Torch Assembly demonstrated in your own shop without charge or obligation. Contact your nearest authorized NCG dealer or NCG district office. Or write for free catalog to address below.

NATIONAL CYLINDER GAS COMPANY

***Executive Offices:* 840 N. Michigan Avenue, Chicago 11, Illinois**

Branches and Dealers from Coast to Coast

NCG®

EVERYTHING FOR WELDING

Copyright 1954, National Cylinder Gas Company

...of cutting production costs!

THESE HANDS are about to *preplace* a ring of EASY-FLO low-temperature silver brazing alloy on a machined part preparatory to heating and joining the part to another.

And how does this simple act cut production costs?
Well, here's how:

Preplacing EASY-FLO is the key factor in a method of joining metals that reduces brazing to push-button simplicity and assures a steady stream of soundly brazed parts—with easily trained labor doing the whole job.

The reduction in time and labor — plus the savings in heat due to EASY-FLO's low brazing temperature—bring brazing costs down to surprisingly low figures.

Will preplacing cut your production costs?

You can find out very easily. One of our field engineers will look over your metal joining work and give you the answer – entirely without obligation. Just write and say when you'd like him to call.

WELDING SHOW BUFFALO

VISIT OUR BOOTH SEE the preplacement method in action on an actual production brazing setup. Also a cemented carbide tip brazing demonstration. Examine the many interesting examples of silver brazed parts from many industries. Talk over your metal joining problems with our brazing engineers who will be there for that purpose.

For the full facts in print, write for a copy of Bulletin 20

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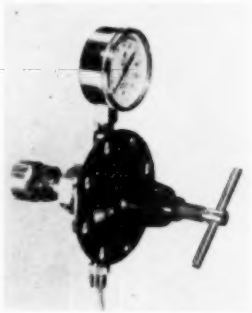
New Pipe-Line Regulators

A new 8900 series of regulators has been announced by Air Reduction to supersede their 8600 series. This new series is designed for use with gases supplied by pipe-line systems using comparatively low pressures.



Regardless of fluctuation in the line pressure, these regulators accurately maintain a steady gas pressure thereby eliminating the need for frequent regulator adjustment. They are of the inverse-type design and feature a novel seating arrangement which requires no nozzle.

Long service life, trouble-free operation and ease of repair are characteristics of the 8900 series of regulators.

For complete details on this series of regulators, request a copy of catalog ADC 705, by writing Air Reduction Sales Co., 60 E. 42nd St., New York 17, N. Y.

Arcair J-5 Torch

A new Model J-5 Arcair Torch for heavy-duty work has been added to the line of cutting and gouging torches manufactured by the Arcair Co. of Lancaster, Ohio, and Bremerton, Wash.

Simplicity, low original cost and low maintenance cost distinguish this new heavy-duty model. Like all Arcair torches the Model J-5 is designed to cut and gouge all metals using only electric arc and compressed air.

The Model J-5 features solid, one-piece insulated head that holds the electrode at a fixed angle to provide better electrode contact and less heat. A spring loaded plunger holds the electrode firmly in place and also acts as automatic air valve. The air is on as long as the electrode remains in the torch.

More information on the new Model J-5 and other Arcair torches can be obtained by writing the Arcair Co., P. O. Box 337, Lancaster, Ohio.

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SECTION NEWS AND EVENTS

as relayed to C. M. O'Leary

Baseball and Titanium

Baltimore, Md.—The February meeting of the *Maryland* Section held on the 19th at the Engineers Club, covered presentations by two speakers which should be considered as both bad news and good news to other AWS Sections.

The bad news came through the medium of the coffee speaker, Rudie Schaffer, Chief Ticket Representative of the new Baltimore Orioles Baseball Club. Bad news, that is, to all clubs condemned to meet the Orioles. If spirit, enthusiasm and the will-to-win as described by Mr. Schaffer are an indication of results then the "Birds" will certainly be bad news to all comers.

The good news is the report that the technical speaker, John C. Barrett, of the U. S. Bureau of Mines contributed greatly to the advancement of welding by delivering his paper on the "Fabrication and Uses of Titanium." Although the uses of titanium have been well publicized and the high technical aspects covered, Mr. Barrett brings the bare facts down into layman's language and presents titanium, not as a wonder metal, but as a material with very definite do's and don'ts.

He described the reasons for the use of titanium, how it can successfully be formed and fabricated, the manner in which it can be welded and also gave descriptions of the laboratory experiments which proved his statements. Mr. Barrett's talk certainly emphasized the fact that laboratory investigations can place practical information into the hands of productive organizations so that products may be produced with a minimum of guesswork. The number and scope of questions directed to the speaker gave indication of the popularity of his presentation and was doubly emphasized by the small group conversations during the refreshment period following the technical session.

Chairman Harrison Sayre thanked the speakers and gave a brief talk concerning each member's responsibility to the Society by contacting prospective new members.

High Temperature Service

Bethlehem, Pa.—"Metallurgical Problems in Welding for High Temperature Service" was the subject of a talk given by R. W. Emerson AWS, of the Pittsburgh Piping and Equipment Co., at the February 1st dinner meeting of the *Lehigh Valley* Section held at Walp's Banquet Hall in Allentown. A sound color film on "Bridge Construction" was also shown.

Weld Inspection Symposium

Boston, Mass.—The February meeting of the *Boston* Section was held at the Alfred P. Sloan Processing Lab., Cambridge, Mass., on Feb. 8, 1954.

Following refreshments and an excellent dinner, Robert Lowrie, of the New England Telephone & Telegraph Co., gave a talk on the Telephone Co.'s microwave relay system, the transmission of telephone conversation and television programs. It was accompanied by a demonstration of the behavior of beam transmission, and a movie entitled "Stepping Along with TV."

Mr. Lowrie was assisted by the Messrs. Conway, Rafferty and Brennan of the Telephone Co.

The coffee talk was followed by a symposium on weld inspection with Harry Udin AWS, of MIT, as moderator and a panel consisting of Allen Hogaboom AWS, of Bethlehem Steel, Quincy, Mass., A. R. Hochhalter of Thompson Electric Welder Co., Lynn, Mass., and Richard S. Tobin AWS, of Power Piping Corp., Cambridge, Mass.

After a brief talk from each of the members of the panel, a discussion period was held.

One hundred and thirty-one members and guests were present at dinner and 141 attended the technical meeting which followed.

New Welding Development

Buffalo, N. Y.—First Vice-President J. H. Humberstone AWS, of the Air Reduction Co., was the speaker at the January 28th meeting of the *Niagara Frontier* Section, held at the Sheraton Hotel with an attendance of 93 members and guests. Mr. Humberstone spoke on "New Developments in Welding."

A plant visit to Harrison Radiator Co., Lockport, N. Y., was made by 53 members of the Section.

Welding Fittings

Buffalo, N. Y.—The *Niagara Frontier* Section held its February meeting on the 25th at the Sheraton Hotel. Ninety-nine members and guests were present at the technical meeting to hear Dan R. Cheyney, Tube Turns, Inc., Louisville, Ky., give some valuable information on the subject "Alloy Welding Fittings."

An attendance of 71 was present at dinner. I. Morrison was roundly applauded for securing ten new members in a recent membership drive in which a total of 27 new members were obtained.

Design for Welding

Chicago, Ill.—An excellent paper on "Product Design for Welding" was given by John Mikulak AWS, Worthington Corp., at the regular monthly dinner meeting of the *Chicago* Section, held on February 19th. Mr. Mikulak's talk included a series of very good slides.

An interesting sound color film, entitled "Wings to Hawaii," was shown prior to the meeting.

Cost Control

Cincinnati, Ohio.—A joint meeting of the AWS and ASM *Cincinnati* Sections was held on February 12th and was one of the more successful meetings of the year. The dinner and the coffee speaker were excellent. Dr. F. L. Culbert's talk on what the men had to go through to watch an atomic explosion was well received.

Leslie S. McPhee AWS, Whiting Corp., Harvey, Ill., gave an excellent discussion on "Welding Cost Control." His formula, which he developed, caused much comment. The talk stressed the various facts leading to profit.

Educational Series

Cleveland, Ohio.—The *Cleveland* Section has sponsored a very successful Educational Series open to the members and the public. Five sessions were planned and the subjects were as follows:

January 8th—"Gas Welding," Jack Twohey, Engineering Representative, Linde Air Products Co.

January 15th—"Electric Arc Welding," Tom Dempsey AWS, Welding Engineer, Lincoln Electric Co.

January 22nd—"Inert Arc Welding," H. T. Herbst AWS, Works Manager, United Tube Corp.

January 29th—"Resistance Welding," Paul Giles AWS, Welding Consultant, Battelle Memorial Institute.

February 5th—General Session at one of Cleveland's industrial plants.

At the last meeting the class saw welding as applied to high production at the Fisher Body Division of General Motors Corp. in Cleveland.

The classes which were held in conjunction with Fenn College in Cleveland had an average attendance of over 40. The Director of the Technical Institute was Nicholas Rimboi of Fenn College, and the project was carried out under the supervision of William E. Mumford of the Educational Committee of the AMERICAN WELDING SOCIETY, Cleveland Section.

Fillerare Process

Columbus, Ohio.—The Ohio State University Student Branch was host to the *Columbus* Section at a dinner meeting on February 12th at the Ohio Union on the campus. The technical speaker was R. W. Tuthill AWS of the General Electric Co.'s Welding Division at York, Pa. Mr. Tuthill's talk entitled "The Fillerare Process" described the consumable electrode inert-gas-shielded arc-welding process in which the arc voltage remains constant. With constant arc voltage the welding current is related to the burn-off rate in the process. The proper burn-off rate is one where the metal comes off the end of the electrode in fine droplets. This rate is a very high one for small wire. Mr. Tuthill described the process in detail in the February 1954 issue of THE WELDING JOURNAL.

The coffee speaker for the evening was the distinguished Dean Gordon Carson of the College of Engineering at the Ohio State University. Dean Carson's talk, entitled "Looking Ahead," brought out the fact that there are many new developments for the future that seem fantastic in this day and age. He pointed out that because of the new developments to be made, there is unlimited opportunities for technical people of today.

Program Schedule

Dayton, Ohio.—Program schedule for the remainder of the season of the *Dayton* Section is as follows:

April 13th—"Tooling for Automatic Welding," Anthony K. Pandjiris.
May 11th—Plant visitation—to be announced.
June 8th—Annual picnic.

Selection of Welding Processes

Dayton, Ohio.—Second Vice-President, John J. Chyle AWS, Director of Welding Research, A. O. Smith Corp., gave an outstanding talk on the subject "Factors in the Selection of Welding Processes" at the February 9th meeting of the *Dayton* Section, held at the Dayton Engineers' Club.

Mr. Chyle's talk covered the various major welding processes in commercial use today, and what factors must be evaluated in selecting the most suitable one to use. The costs involved, engineering design, service requirements and other factors were considered in order to show the role they play in selecting the process which will give the desired weld at the most economical price. Slides were shown to illustrate the talk.

Prior to the technical meeting, a sound color film entitled "Prevention and Control of Distortion in Arc Welding" was shown through the courtesy of the Lincoln Electric Co.

Weldability

Decatur, Ill.—The February 16th meeting of the *Sangamon Valley* Section was addressed by J. Heuschkel AWS, of the Westinghouse Corp., on the subject "Weldability, an Independent Approach." Slides and motion pictures were used to illustrate this excellent talk. The meeting was held at the St. Nicholas Hotel in Decatur.

X-Ray

Denver, Colo.—William S. Smith AWS, of the Industrial X-Ray Engineers, Denver, at the February 9th dinner meeting of the *Colorado* Section, gave an extremely interesting talk on "X-Ray"; what it accomplishes and its possibility as portable equipment for pipe lines, refinery equipment and many other applications.

Welding Metallurgy

Des Moines, Iowa.—February's meeting for the *Iowa* Section was again held at the New Pastime Club in Des Moines. On hand the evening of the 18th was a good attendance to hear Anton Schaeffler AWS, Welding Research Engineer, of Allis-Chalmers Manufacturing Co. The topic chosen by Mr. Schaeffler was "Metallurgy as Applied to Welding."

An understanding of the fundamental metallurgical transformations during the welding of mild steels and low-alloy steels can greatly aid the welder in improving the ductility qualities of joints. By the second weld pass and subsequent passes of the metallic arc process, the fine grain structure required of ductile joints is advanced to the optimum. The coarse as-cast structure present in the initial pass is eliminated during the heat application of these latter passes due to an "annealing effect" over a longer period of time.

Mr. Schaeffler broke down the various heat levels in a weld nugget and established their relation on the complicated transformation curve for mild steel. Special coloring applied to the various heats were shown on diagrams of a nugget

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cross section. Reference then to the transformation chart which was similarly colored made the explanation of heat transformation easily understood.

When special conditions exist in welding such as those involving free machining steels, enameling steels or joints subject to impact, the use and advantages of the low-hydrogen type electrodes was explained. The control of the formation of hydrogen sulfide gases is important in such cases and by using electrodes with coating low in hydrogen the porous conditions often encountered can be eliminated.

Though fringing on technical information, Mr. Anton's speech was well received by an audience representing a wide cross section of welding personnel.

Metallurgy

Erie, Pa.—The February 17th dinner meeting of the *Northwestern Pennsylvania* Section held at Sadler's Cafe, Erie, was addressed by R. D. Wylie of the Babcock & Wilcox Co. Mr. Wylie gave an excellent extemporaneous talk on "Metallurgy."

Through the courtesy of the U. S. Steel Co., a sound color film, entitled "Bridging San Francisco Bay," was shown following the meeting.

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Hard Surfacing

Grand Rapids, Mich.—Al Patnik of the Lincoln Electric Co., Cleveland, Ohio, was both coffee and technical speaker at the February 22nd dinner meeting of the *Grand Rapids* Section, held at the Varsity Grille.

Mr. Patnik is a diving champion. He has held more diving titles than any other human and is the holder of the Grand Slam Championships. Mr. Patnik related his experiences while on tour through Europe with a diving troupe.

As technical speaker, Mr. Patnik very capably covered the subject "Hard Surfacing and Its Applications." Mr. Patnik is located in Cleveland as Hard Surfacing Manager of the Lincoln Electric Co. for the entire U. S.

Submerged Arc Welding

Houston, Tex.—An attendance of 130 were present on February 24th at the *Houston* Section meeting held at the Ben Milam Hotel to hear D. C. Ransone AWS, Linde Air Products Co., Kansas City, Mo. Mr. Ransone presented an excellent, semitechnical discussion on "General Methods with Submerged Arc Welding."

An attendance of 125 were present at the dinner preceding the meeting at which time a film, entitled "Via Mexico," was shown through the courtesy of Association Films, Inc., Dallas, Tex.

Sabine Division

Houston, Tex.—The second meeting of the *Sabine* Division of the *Houston* Section was held on Thursday, February 25th in the Sky Room of the Edison Hotel, Beaumont, with an attendance of 95 at the dinner and 110 at the technical session. This Division now has 83 members with about ten more ready to join.

An excellent, semitechnical discussion on "Submerged Arc Welding" was given by D. C. Ransone AWS, Linde Air Products Co., Kansas City, Mo.

A sound color film, entitled "Prevention and Control of Distortion," was shown through the courtesy of the Lincoln Electric Co.

Activation Meeting

Marion, Ohio.—The Activation Committee meeting of the Marion Branch of the *Columbus* Section was held on Friday evening, Jan. 15, 1954, at the office of the Marion Power Shovel Co. Those in attendance were: B. G. Bishop, Baldwin-Lima-Hamilton Corp.; Howard B. Cary, Marion Power Shovel Co.; Robert Ellison, Metal & Thermit Co.; Robert W. Kennedy, Wireweld Co.; Terry Long, GarWood Industries; Finley Marshall, Marion Power Shovel Co.; O. C. Rowlinson, Ohio Locomotive Crane Co.; Walter Slob, Slob & Bierce Welding Co.; V. L. Woodward, Baldwin-Lima-Hamilton Corp; C. W. Ziegler, Marion Power Shovel Co.

The above will form a portion of an Activating Committee for the purpose of forming a Section of the AMERICAN WELDING SOCIETY. The other members of the Committee are: R. E. Beam, W. A. Riddell Corp.; J. E. Dipert, GarWood Industries; A. F. Fitch, Hanson Clutch &

Members of the Milwaukee Section enjoying the Miller Brewing Company's famed hospitality at the Section's January 22nd meeting held at Miller Inn. Left to Right: Don Wilson, Vice-Chairman; Elmer Klumpp, John Linnehan and Werner Gallo, Chairman

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Officers of the Activating Committee were selected and are as follows: R. A. Ellison, *Chairman*; V. L. Woodward, 1st Vice-Chairman; O. C. Rowlinson, 2nd Vice-Chairman; Howard B. Cary, Secretary; and Robert W. Kennedy, Treasurer.

Mr. Ellison reviewed correspondence received from J. G. Magrath, National Secretary; J. H. Blankenbuehler, District Vice-President and Mel Clapp, Chairman, Columbus Section.

It was unanimously decided by all present that a Section of the AMERICAN WELDING SOCIETY would be supported in this area. It was felt that the area should be bounded by Lima and Wapakoneta on the west, Findlay and Tiffin on the north, Ashland and Mount Vernon on the east and Marion and Mt. Gilead on the south.

A quick count revealed approximately 70 present and prospective members living in the area.

It was felt that the Section should, at least at the start, be a branch of the Columbus Section.

Membership enrollment is to start at once with the objective to obtain 60 members by March 12th. It was decided to send all membership applications to the Activation Committee Secretary and for him to hold them until the next meeting to be held March 12th. Activation Committee members living in the various cities in the area are to approach the chief executives of companies using welding, to enlist their aid.

The March 12th meeting of the Activation Committee will be held preceding the regular meeting of the Columbus Section.

This Columbus Section meeting will be held in Marion and will include a tour through the Marion Power Shovel Co. An extensive publicity drive will be made.

Meetings to Date

Minneapolis, Minn.—The *Northwest* Section reports on its recent meetings as follows: The December meeting was held December 14th in the Covered Wagon in Minneapolis, and the speaker was F. H. Stevenson AWS, Production Engineer for Aerojet-General Corp., Azusa, Calif. He spoke on the subject of forming and welding titania. The "Happy Half Hour" for this meeting was sponsored by National Cylinder Gas Co.

The annual Christmas party was held Friday evening, December 18th, at the Francis Drake Hotel, Minneapolis. This was the most successful and had the greatest attendance in the history of the Northwest Section.

The January meeting was in the form of a plant tour and the Section met January 11th at 3:00 P.M. and toured the St. Paul plant of the Ford Motor Co. Dinner was held in the company cafeteria that evening at which time the Section was welcomed by Robert Elliott, Plant Manager of the Ford Motor Co. This was followed by a showing of a movie covering transportation through the last 50 years.

The February meeting was held February 8th. The speaker was Roger Babcock AWS, Laboratory Division Head of the Linde Air Products Co., Newark, N. J. He spoke on the subject "Recent Developments in Powder Cutting Processes." The "Happy Half Hour" preceding the dinner was sponsored by Linde Air Products Co. Mr. Hanson, Section Chairman, paid tribute at the meeting to Marcus Maynard AWS, Instructor of Dunwoody Institute. Mr. Maynard is leaving for Indonesia to spend two years in instruction work under a Ford Foundation grant.

Welding Stainless Steels

Newark, N. J.—Approximately fifty members and guests of the *New Jersey* Section turned out for the regular February dinner meeting, held on the 16th, at the Essex House at Newark to hear George E. Linnert AWS, Research Welding Metallurgist, tell about "Recent Developments in Welding Stainless Steels." Mr Linnert spoke from a broad background in industry, including the last eleven years spent with Armco Steel Corp. During World War II, he conducted several research projects for the National Defense Research Council and the Office of Naval Research. He has taught classes in "advanced" welding metallurgy at the Johns Hopkins University.

Mr. Linnert's talk touched off one of the longest and liveliest question-and-answer periods of the season's activities, and certainly there can be no better measure of the interest developed.

Welded Ship Repair

New York, N. Y.—"Interesting Problems in Welded Ship Repair" was the title of the paper presented at a joint meeting of the *New York* Section AWS and the New York Metropolitan Section, Society of Naval Architects and Marine Engineers, on February 16th.

The speaker was Milton Forman, Consultant Welding Engineer, who is a member of the New York Section AWS. Mr. Forman has had over 15 years' experience in shipbuilding and ship repair, having held the position of Welding Engineer with the Toledo Shipbuilding Corp., Ingalls Shipbuilding Corp., Matson Navigation Lines, and Todd Shipyards Corp.

In his talk, Mr. Forman pointed out that ship repair problems are very different from those encountered in new construction, and that in the repair of a ship the work has to be done on an existing, rigid structure. This fact introduces many new problems in that welding is always

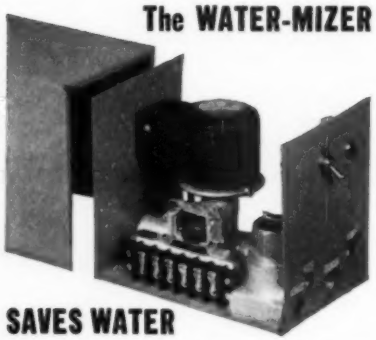
accompanied by shrinkage and contraction. In his talk, Mr. Forman discussed some of the methods used in reducing distortion in making large-scale welded repairs. He also suggested some improved design details and outlined some improved methods for repairing shafts and stern frames. The paper was very well received by the large audience, and an interesting discussion period followed.

This year the New York Section of the AMERICAN WELDING SOCIETY played host at this meeting, with the members of the New York Metropolitan Section of the Society of Naval Architects and Marine Engineers as our guests. The Chairman of the New York Section, AWS, greeted the audience and welcomed our guests, stating that this joint meeting was always regarded as one of the high lights in our yearly program. G. H. Copenhaver, New York Naval Shipyard, Chairman of the Society of Naval Architects and Marine Engineers, spoke briefly in reply and expressed their pleasure in meeting with us again. F. J. Crum, American Bureau of Shipping, served as Technical Chairman for the meeting.

A new member of the SOCIETY, Lionel V. Martin, was the guest of the Section at this meeting. He was introduced to the members present, and received a warm round of applause.

The Chairman announced the formation of a Long Island Division of the New York Section of the AMERICAN WELDING SOCIETY. This Division is presently being organized, and tentative plans call for the inaugural meeting to be held on Apr. 27, 1954, at Westbury, L. I. The membership of the Section will be notified as to the place and subject of the meeting in the near future. E. W. Moles is in charge of the Committee organizing this Long Island Division.

The meeting was held at Schwartz's Restaurant, 54 Broad St., New York City, where dinner was served prior to the technical session.



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Inert Arc Welding

Oak Ridge, Tenn.—Glenn J. Gibson AWS, Project Engineer with the Cooper Alloy Foundry Co., Hillside, N. J., spoke before the *Northeast Tennessee* Section on February 17th on the subject "Fundamentals of Inert-Gas-Shielding Tungsten-Arc Welding Process."

Mr. Gibson's background includes B.S. and M.S. engineering degrees from Lehigh University and over seventeen years of welding research work with Pittsburgh-Des Moines Steel Co., American Bridge Co. and Air Reduction. He helped develop the widely used inert-gas-shielded metal-arc welding process, and is currently engaged in a concentrated research program to develop improved methods for welding high-alloy material.

Fabricating Electric Motors

Pascagoula, Miss.—"Fabricating as Related to the Manufacture of Electric Motors" was the subject of a talk given by G. H. Gefvert AWS, Reliance Electric and Engineering Co., Cleveland, Ohio, at the February 3rd dinner meeting of the *Pascagoula* Section, held at Ingalls Shipyard Cafe.

A Navy film, entitled "The Submarine," was shown after the meeting.

Electrodes

Phoenix, Ariz.—The *Arizona* Section held its regular monthly meeting at the Hotel Westward Ho on February 17th. Following dinner a very unusual presentation on "Recent Developments in Alloy Electrodes" was made by Richard K. Lee AWS, Vice-President of Alloy Rods Co. Mr. Lee's slides were particularly helpful as well as his film, "No Finer Electrode Made," in giving those present a good understanding of the progress made in the art of manufacturing electrodes. The Section is indebted to Mr. Lee for his gracious visit and all agree the evening was very interesting and enlightening.

Stainless Steel

Pittsburgh, Pa.—Following a "Get-Together" dinner at which new members of the *Pittsburgh* Section, invited guests and friends, were introduced by Chairman Kauffman, the February 17th meeting got under way with an attendance of 108.

George Edwin Linnert AWS, Research Welding Metallurgist, Armco Steel Corp., Baltimore, Md., discussed the subject "Fabrication of Stainless Steel" from the standpoint of the materials involved in cutting and welding more than the welding processes and techniques. Proper procedures for joining a number of grades, like the free-machining types, the extra-low-carbon grades, and the new precipitation hardening alloys, were covered. The composition and performance of stainless steel arc welding electrodes were also discussed. The proper steps for avoiding difficulties during welding or in subsequent service were discussed using illustrations and actual case histories.

Mr. Linnert also discussed the problems related to the fabrication and heat treatment of the new precipitation hardening alloys, 17–4 PH and 17–7 PH.

A Pennsylvania State University film, "Elements of Hardening," was shown before the meeting.

Ladies' Night

Saginaw, Mich.—The annual Ladies' Night Dinner Dance of the *Saginaw Valley* Section was held February 13th at Rolling Green Country Club in Saginaw. Approximately 136 couples were present and all enjoyed the buffet-type dinner. Dancing followed after everyone had their fill. A corsage was given to every lady present and door prizes were awarded to winning couples. The turnout for this affair was outstanding and this was accomplished by the hard work of all members who donated their efforts in making this a huge success.

Weld Seam Corrosion

St. Louis, Mo.—A joint meeting of the *St. Louis* Section with the NACE was held on January 21st at the Engineers' Club of St. Louis with an attendance of 175. Technical speaker was A. J. Liebman of Pitmar Centrifugal Machinery Corp., whose subject was "Weld Seam Corrosion and Its Control."

Mr. Liebman's talk dealt with the factors causing weld seam corrosion in mild carbon steel; namely, weld flux slag, weld flux deposits, weld heat oxide and weld spatter. He pointed out how this corrosion takes place adjacent to the seams, rather than in the seams themselves.

The steps to be taken to prevent this corrosion, both under paint films and on unpainted metal, were discussed.

Of particular interest was his description of the benefits to be obtained from new

wetting oils soon to be put on the market. Also of interest was his description of the deleterious effects to be obtained from improper use of power wirebrushing.

Corrosion

Salt Lake City, Utah.—A dinner meeting of the *Salt Lake City* Section was held on January 28th at the Doll House with an attendance of 80 at the dinner and meeting. Mr. La Que of the International Nickel Co., gave an interesting semitechnical talk on the subject "Some Apparent Anomalies in Corrosion."

A sound color motion picture film entitled "Inert Arc Welding of Aluminum" was shown before the meeting.

Clad Steels

Salt Lake City, Utah.—Louis P. Keay AWS, Technical Service Engineer, Lukens Steel Co., Coatesville, Pa., spoke before the February 4th meeting of the *Salt Lake City* Section on clad steels. Mr. Keay explained manufacturing methods, properties, fabrication, application and economics of these steels.

Mechanized Welding

Seattle, Wash.—The regular monthly dinner meeting of the *Puget Sound* Section was held on January 14th at the Engineers' Club. An after-dinner attraction was the showing of a film entitled "Fantasia." Robert Morton AWS, of the Morton Manufacturing Co., spoke extemporaneously on the subject "Application of Machine Tool Fixturing to Mechanized Welding."

Stress Concentration

Sheffield, Ala.—A very excellent presentation of the subject "The Study of Stress Concentration in Weld Design" was given by John E. Durstine AWS, of the Lincoln Electric Co., at the January 28th meeting of the *Tri-Cities* Section at the TVA Auditorium. Dinner at the Muscle Shoals Hotel preceded the meeting.

Cast Welds

Shelton, Conn.—The January 21st dinner meeting of the *Bridgeport* Section was held at Rapps Restaurant in Shelton. Coffee speaker was James Danver, who spoke on the subject "Racing."

Speaker at the technical meeting was James H. Lowe, Product Development Director, SFSOA. "Cast Weld and Composite Fabrication" was the subject of Mr. Lowe's talk.

Welded Steel Structures

Syracuse, N. Y.—The *Syracuse* Section met on February 10th in the Hiawatha Room of the Onondaga Hotel. The principal speaker was Van Rensselaer P. Saxe AWS, Consulting Structural Engineer, who spoke on Welded Steel Structures. In his talk he described the general design of welded structures, their economy and safety, and the speed with which welded structures can be fabricated and erected. He showed a great many slides that were actually taken in the field to demonstrate the general acceptance of welding as a structural fabrication process. Mr. Saxe emphasized that welding requirements were simple to specify and in general closely followed standards established by the AMERICAN WELDING SOCIETY.

It was indeed a pleasure to listen to a speaker with over twenty years of structural welding experience describe some of his more important projects.

Distortion Control

Worcester, Mass.—The regular monthly meeting of the *Worcester* Section was held on January 4th at the Tower House. Prof. Herbert A. Sawyer, Jr., of the University of Connecticut, Storrs, Conn., presented an excellent semitechnical discussion on the subject "Distortion Control of Large Welded Structures."

Weldments

Worcester, Mass.—The February dinner meeting of the *Worcester* Section was held on the 1st, at the Tower House with an attendance of 82 at the dinner and 87 at the technical meeting.

"Weldments" was the subject of a semitechnical talk given by Benjamin Kernisky of the Pullman Standard Car Manufacturing Co.

Tube Welding

Youngstown, Ohio.—The *Mahoning Valley* Section held its January meeting on the 21st at the Mahoning Country Club in Girard, Ohio. A nontechnical talk on "Recent Developments in Tube Welding" was given by Paul J. Abel AWS, Vice-President, Engineering, The Yoder Co., Cleveland, Ohio.

Tool and Die Welding

Youngstown, Ohio.—The *Mahoning Valley* Section held its February meeting on the 18th at the Mahoning Country Club in Girard, Ohio. Patrick S. Doyen AWS, Welding Equipment & Supply Co., gave a extemporaneous talk on "Tool and Die Welding." Slides were used to illustrate Mr. Doyen's presentation.

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abstracts of CURRENT WELDING PATENTS

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Printed copies of patents may be obtained for 25c from the Commissioner of Patents, Washington 25, D. C.

2,667,137—Apparatus for Welding Radiators—Karl Osterman, Stockholm, and Gunnar Arnberg, Lidingo, Sweden, assignors to Svenska Aktiebolaget Gasaccumulator, Stockholm, Sweden, a corporation of Sweden.

This patented apparatus is for welding together the edges of juxtaposed workpieces that present a joint to be welded which includes a curved line in the plane of the weld. The apparatus includes a carriage on which the workpieces are secured, a welding burner and control means for correlating the position of the welding burner and the workpieces.

2,667,559—Method of Welding—Perry C. Arnold, Chicago, Ill., assignor to Chicago Bridge & Iron Co., an Illinois corporation.

Arnold's welding method relates to a process of submerged arc electric welding of a generally horizontal joint between upright plates. The method comprises mounting a carriage on the upper plates to carry a welding head along the joint, correlating the rate of travel of the carriage to the fusion of an electrode carried at the joint by the carriage to deposit a weld bead larger than the welding electrode, and directing the electrode downwardly and rearwardly toward the joint to permit expanding gases to carry metal being deposited toward previously deposited metal and upwardly in the joint into freezing contact with the upper plate. The so deposited weld bead is thus fused by such directing to both the upper and lower plates with the bead having a root width substantially smaller than its outer width to provide cooling of the bead from the root of the joint outwardly.

2,668,273—Voltage Reducing Device for Welding Transformers—Cornelis Pieter Sonius, Groningen, Netherlands, assignor to Vennootschap order firma Oscar Keip, Groningen, Netherlands, a corporation of the Netherlands.

This special transformer and voltage regulating device includes a choke coil connected in the primary of the transformer, a contactor for short circuiting the choke coil and a relay for actuating the contactor. An actuating armature is provided for the relay and has a tendency to move to contact closing position. A voltage coil is connected in parallel with the secondary winding of the transformer and is positioned to magnetically move the actuating armature to contact opening position upon the application of the voltage of the secondary winding thereto. A current coil is connected in the secondary circuit in series with the secondary winding of the transformer and is positioned to magnetically overcome the magnetic effect of the voltage winding and shift the actuating armature to contact closing position upon the flow of current from the secondary winding through such current winding.

2,669,015—Method of Progressively Welding Railroad Car Side Walls—Arthur C. Schanz, Glen Ridge, N. J., assignor to American Car and Foundry Co., New York, N. Y., a corporation of New Jersey.

This patent, as the title indicates, covers a specialized method for progressively welding railroad car side walls into unitary shapes.

2,669,419—Weld in Pipe Line Valve Structure—Farrile S. Young, Houston, Tex., assignor to Panhandle Eastern Pipe Line Co., Kansas City, Mo., a corporation of Delaware.

Young's patent relates to a special valve that is welded within a pipe line and is sealed in the bore thereof by the weld means used to secure the valve within the pipe line.

2,669,467—Welded Tubing End Construction—Edwin C. Wolferz, Nutley, N. J.

This patent is on a tube end construction for connection to an open member to pass material flowing through the tube into the open member. The patent calls for special L-shaped construction made by securing a ring to the tube by a welded joint and other specialized connecting means are called for in the construction.

2,669,639—Method and Apparatus for the Production of Welded Tubing—Howard J. Bowman, East Troy, Wis., assignor to Trent Tube Co., East Troy, Wis., a corporation of Wisconsin.

In this patent, a method for producing welded tubing from metal strip having rounded edges in transverse section is disclosed. The strip is continuously fed in the direction of its length while it is progressively shaped to tubular form. The strip edges adjacent a longitudinal seam formed in the tube is heated to welding temperatures by inducing high-frequency currents therein and such edges are pressed together to weld the mid-sections thereof while slightly upsetting the remaining edge portions to form upset portions on opposite sides of the mid-sections. These upset edge portions are separated by a crevice and thereupon the upset edge metal is flowed into the crevice by further heating interiorly and exteriorly of the tubing until a weld joint is formed substantially flush with the internal and external surfaces of the tubing.

2,669,640—Submerged-Melt Electric Series-Arc Welding—Frederick G. Outcalt, New Rochelle, and Edward L. Frost, Snyder, N. Y., assignors, by mesne assignments to Union Carbide and Carbon Corp., a corporation of New York.

A process of submerged-melt electric series-arc welding is covered in the patent and includes depositing a single bead of metal on a metallic workpiece under flux by relatively moving electrodes and the workpiece along the path to be welded. The electrodes are separately fed toward a common welding zone at rates which are individually governed by the voltage drop between each of the electrodes and the workpiece. Arc welding current is supplied only through the electrodes and the workpiece is excluded from the arc welding current circuit except in the immediate area of the welding zone whereby a minimum amount of penetration and dilution of the workpiece is produced.

2,669,957—Welding Clamp—Hans Joachim de Vogt, Solingen-Ohligs, Germany.

de Vogt's patent relates to a welding

vise which has a base, a pair of arms diverging forwardly from the base and a clamping member. The clamping member is engaged with the remainder of the vise by a threaded bolt which has a handle provided therefor so that rotation of the handle will move the clamping member along the longitudinal axis of the bolt. Flanges are provided on the base arms for cooperating with the clamping member to secure members therebetween.

2,669,958—Welder's Work-Holding Appliance—Charles W. Sweeney, Columbus, Ohio, assignor of 15% to Joseph R. Hague, Columbus, Ohio.

This patented welder's fixture has base means provided therein and two independent and separately adjustably positioned arms are secured to the base and extend up therefrom. These arms carry clamp means thereon for engaging a workpiece to be positioned between a pair of clamps supported by the two arms carried by the base means of the fixture.

2,670,423—Automatic Seam Following Device for Welding Apparatus—Frederic M. Darner, Shaker Heights, Ohio, and Walter S. Schaefer, East Gadsden, Ala., assignors to Republic Steel Corp., Cleveland, Ohio, a corporation of New Jersey.

In this patent, apparatus is provided for manufacturing pipe from a tubular blank having a longitudinal cleft therein. A stationary welding chuck is provided through which the blank is advanced axially and a welding device is mounted on the chuck for movement transverse to the path of advancement of the blank and operable when aligned with the cleft to close it by welding a seam therealong as the blank advances. Reversible motor means are present in the apparatus for moving the welding device transversely to the path of movement of the blank and means control operation of the motor means to maintain the welding device in desired alignment with the cleft in the blank.

2,670,424—Method of Electric Arc Welding of Metal or Alloy Studs and the Like to Metal or Alloy Plates and the Like—Harold Martin, East Molesey, England.

In this welding method, a conducting relation is established between one end of a metallic object having its end completely metallized with a metallic material of higher electrical conductivity than that of the object and selected from the group consisting of aluminum, titanium, vanadium and manganese and their alloys, and the surface to which it is to be welded. A welding current is passed through the object and the surface and forms an arc between them, which arc is maintained for a predetermined period so that the welding end of the object and the crater formed in the surface may acquire welding temperatures. The heated object then is moved into contact with the crater and flow of current in the welding circuit through the object and surface is maintained as long as necessary to secure a satisfactory weld.

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O'Mahony, Charles (C)

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Stroud, Richard R. (C)

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Messinger, Justin C. (B)
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Wadsworth, William F. (B)

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Oliver, William C. (C)

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Hanshaw, F. R. (B)

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Erickson, Hilbert (B)

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Engstrom, Harold (B)
Hudson, Murray (C)
de Espregueira Mendes, Roberto (B)
Pozzi, Carlo A. (C)
Satterstron, John E. (C)
Scarr, Peter R. R. (C)
Stiepewich, H. J. (C)
Vollmaier, Alfred (B)
Tripiciano, Dott. Enrico (B)

Members Reclassified

During the month of February

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Stevenson, Arthur M. (C to B)

PHILADELPHIA

Holzbauer, A. A. (B to A)
Jackson, T. M. (A to F)

SOCIETY

Lang, Florian G. (C to B)

SYRACUSE

Miller, Harry E. (C to B)

SANGAMON VALLEY

Myers, Jeremiah W. (C to B)

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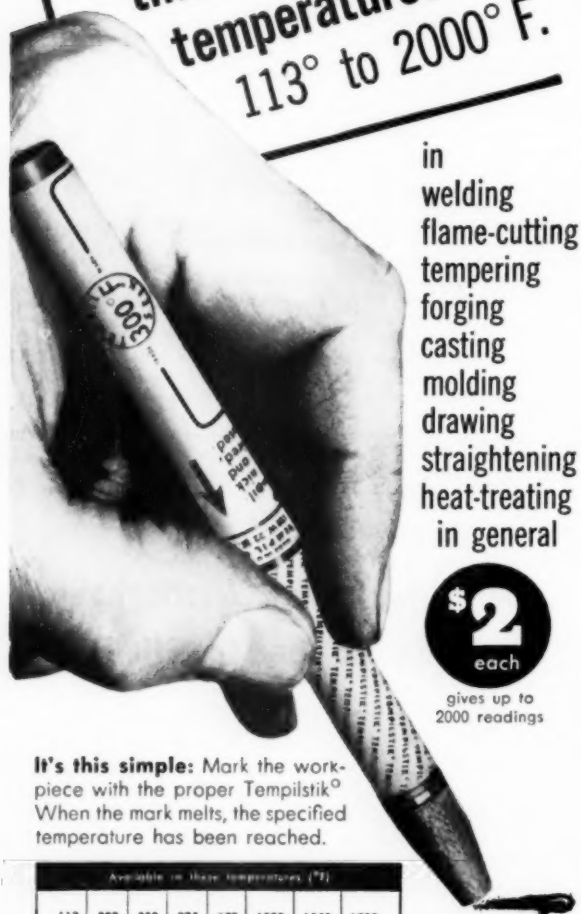

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Supplement to the Welding Journal, April 1954

Effect of Low-Temperature Stress-Relieving on Stress-Corrosion Cracking

Controlled low-temperature stress-relieving was found to be effective in protecting welded plates from stress-corrosion cracking

by C. R. McKinsey

Abstract

Tests made under laboratory conditions showed that residual welding stresses were sufficiently high to cause stress-corrosion cracking in some steels when exposed to a mixed nitrate solution. Both rimmed and killed steels were shown to be susceptible, and the carbon content appeared to have some effect. Controlled low-temperature stress-relieving was found to be effective in protecting welded plates from stress-corrosion cracking. The laboratory tests were supplemented by field tests in which specimens were immersed in a large storage tank containing 85% ammonium nitrate solution for a period of 10 months. Severe cracking took place in the as-welded plates but not in the low-temperature stress-relieved plates.

INTRODUCTION

STRESS-CORROSION cracking has been defined as "cracking resulting from the combined effects of corrosion and stress."[1] A well-known example of stress-corrosion cracking in steel is the caustic embrittlement of boilers. Not only caustic solutions, but also certain nitrate solutions[2, 3] and even crude coke-oven gas[4] have been found to produce cracking of this type in low- and medium-carbon steel plate.

A consideration of the theory of stress-corrosion cracking is beyond the scope of this paper, but the principal theories have been reviewed by Harwood.[5] Although none of the presently developed theories has been universally accepted, it is generally agreed that susceptibility to stress-corrosion cracking depends on several factors such as metal composition, stress level, corrosive medium, temperature and time. These factors are not mutually independent. It has been said that either internal or applied tensile stresses must be present at the surface if stress-corrosion cracking is to occur.[6] Welded structures have been found to be vulnerable to stress-corrosion cracking because of the high residual stresses which are normally present.[4, 7, 8]

A common method of combatting stress-corrosion cracking is to keep the tensile stresses at a low level. In the case of residual welding stresses, this means that some sort of stress-relief treatment would be required, and the beneficial effect of standard high-temperature stress-relieving has been demonstrated.[4, 8] The controlled low-temperature stress-relieving process was designed not only for structures too large to be conveniently furnace stress-relieved but also for use when furnaces are not available or are uneconomical to use. It has been shown that this process effectively relieves stresses,[9] so it would seem logical that it should be a beneficial treatment for welded structures exposed to corrosive media. This paper describes a number of tests made to determine the effect of low-temperature stress-relieving on the stress-corrosion cracking of welded steel plates.

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Presented at the Thirty-Fourth National Fall Meeting, AWS, held in Cleveland, Ohio, week of Oct. 19–23, 1953.

Table 1—Composition and Mechanical Properties of Steel Plates

Steel no.	Chemical composition, %								
	C	Mn	Si	S	P	Cr	Cu	Ni	Al
3	0.082	0.37	0.49	0.037	0.077	0.80	0.44	0.52	0.044
7	0.10	0.61	0.29	0.031	0.13	0.57	0.64	0.31	0.049
12	0.24	0.39	0.16	0.027	0.021	0.037	0.023	Tr*	0.005
16	0.16	0.45	<0.01	0.038	0.014	0.056	0.14	0.11	...

Steel no.	Mechanical properties†			
	Yield point, psi	Tensile strength, psi	Elongation, %	Reduction area %
3	48,100	67,200	38.6	73.8
7	57,700	79,550	34.0	67.7
12	36,300	63,600	37.3	62.2
16	32,700	57,300	39.4	66.5

* Tr = trace.
† 0.375-in. diam specimens.

MATERIALS

The chemical compositions and tensile properties of the four steels used in this investigation are given in Table 1. All plates were 1/2 in. thick. Steel Nos. 3 and 7 were low-carbon, low-alloy steels, No. 12 was a plain carbon fully killed steel and No. 16 was a plain carbon rimmed steel.

The test specimens contained submerged arc butt welds of sufficient size to develop maximum residual stress.[11] No stress measurements were made during this investigation, but previous experience indicated that the maximum residual stress would be of yield point magnitude. The actual maximum stress values were probably in the range of 35,000 to 55,000 psi, among the four steels.

In order to obtain cracking within a reasonable length of time, it was necessary to use a strongly corrosive solution. A mixed nitrate solution consisting of 60% $Ca(NO_3)_2$ and 3% NH_4NO_3 with 37% water was chosen since it had been reported that cracking caused by both caustic solutions and nitrate solutions was similar in kind and degree,[10] and severe cracking had been obtained in welded steel plates after relatively short exposures to the above solution.[4] The tests were conducted at atmospheric pressure with the solution at the boiling point, which was about 120° C.

STRESS-RELIEVING PROCEDURE

The low-temperature stress-relieving was done with a standard hand-type assembly mounted on a machine carriage, as shown in Fig. 1. The manner in which this process relieves stresses has been fully described by Greene and Holzbaur,[9] and their recommended procedures were closely followed. In stress-relieving plates of this thickness, a 4- to 5-in. wide band on each side of the weld is heated to between 350 and 400° F. In normal practice, the structure is large enough to dissipate the heat away from the torch-heated zone rapidly and uniformly, so that a constant rate of travel speed results in a constant maximum temperature as the torches proceed down the weld. However, the largest test plate in this investigation was only 2 ft wide, and the heat tended to build up in the plate and increase the maximum temperature as the torches progressed.

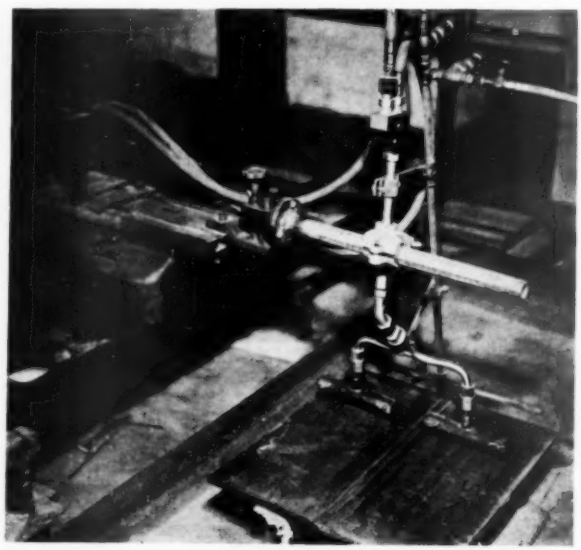

Fig. 1 Low-temperature, stress-relieving equipment

Therefore, conditions were adjusted so that the proper temperature was obtained over the major portion of the plate length, thus causing slight underheating at the beginning and slight overheating at the end. This would result in somewhat higher-than-normal stresses near the beginning of the plate while compressive stresses would be introduced near the end. Under optimum conditions, the stresses are reduced to less than 5000 psi, tension.[9]

TEST PROCEDURE AND RESULTS

Two submerged arc welds were made in Steel No. 16, each weldment measuring 1/2 by 20 by 20 in. One of the specimens was low-temperature stress-relieved, and the other was left as-welded.

The two specimens were then immersed in a tank containing the boiling nitrate solution. They were removed and examined at intervals of 49-hr, 97 1/2-hr and 200-hr exposure. After 49 hr, a few very small cracks were detected in the heat-affected zone of the as-welded plate. No cracks could be found in the stress-relieved specimens. After 97 1/2 hr, the cracks in the

Fig. 2 As-welded specimen, Steel No. 16, after a 200-hr exposure to mixed nitrate solution. Extent of cracking equaled 15.4 in.

as-welded specimen had propagated considerably, and after 200 hr the cracks were quite large. Figure 2 shows the top of the as-welded plate after a 200-hr exposure. The total linear inches of cracking was 15.4, and the cracks extended completely through the plate. No cracks were found in the stress-relieved plate, and the benefit of this treatment is apparent.

Metallographic examination disclosed the predominantly intergranular nature of the cracks, and typical areas in the weld metal and base metal are shown in Figs. 3 and 4.

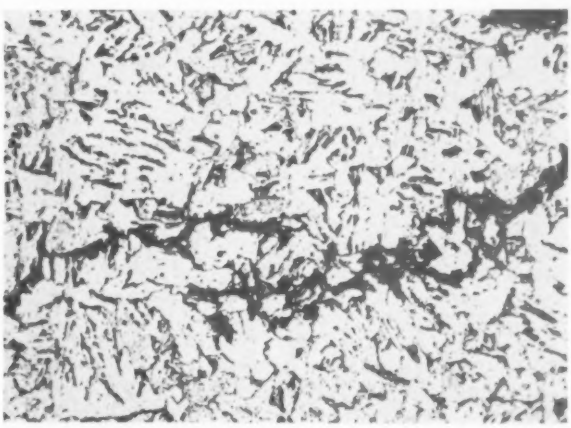

Fig. 3 Section of crack in as-welded specimen, Steel No. 16, showing propagation in weld metal. × 250

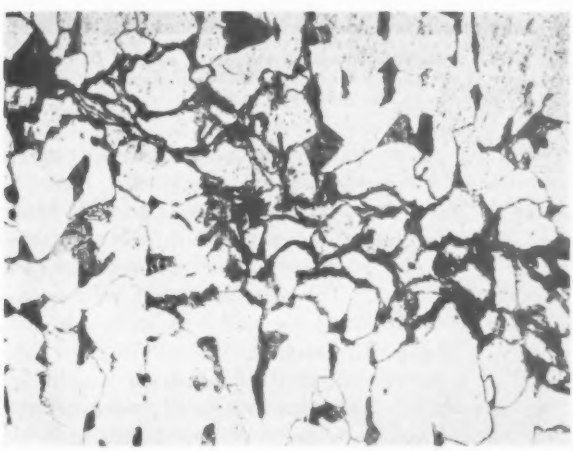

Fig. 4 Section of crack in as-welded specimen, Steel No. 16, showing propagation in base metal.. × 250

Two more submerged arc welds were made in Steel No. 12, the weldments again measuring $^1/_2$ by 20 by 20 in. One of these was low-temperature stress-relieved, and the specimens were immersed in the nitrate solution as before for a total of 455 hr. No cracks appeared in either specimen. Apparently, Steel No. 12 was less susceptible to cracking than Steel No. 16.

Two more welds were prepared, using Steel No. 3. The weldments measured $^1/_2$ by 18 by 20 in. One of them was stress-relieved, and both were immersed in the nitrate solution. This steel proved very susceptible to cracking, and after a $70^1/_2$-hr exposure, the as-welded plate contained 101 in. of cracking. The top of this plate is shown in Fig. 5 and the bottom in Fig. 6.

Fig. 5 Top of as-welded specimen, Steel No. 3, after a $70^1/_2$-hr exposure to mixed nitrate solution. Extent of cracking equals 101 in.

Fig. 6 Bottom side of as-welded plate, Steel No. 3, after a $70^1/_2$-hr exposure to mixed nitrate solution, illustrating propagation of cracks through plate thickness

Nearly all the cracks extended completely through the plate. It may also be noted that several cracks were formed at the edges of the plate. Apparently the stresses produced by flame cutting were sufficient to cause cracking in this steel.

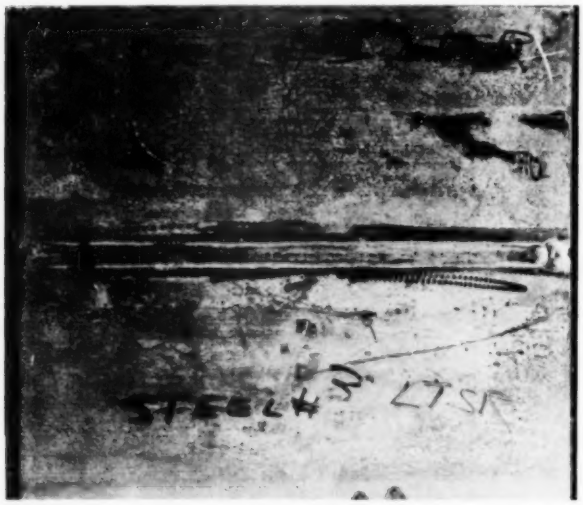

Fig. 7 Low-temperature stress-relieved specimen, Steel No. 3, after a 70½-hr exposure to mixed nitrate solution. One crack, 2.4 in. long, in designated area

A small crack also developed near one end of the weld in the stress-relieved specimen, as shown in Fig. 7. The crack was 2.4 in. long and extended completely through the plate. Apparently, the temperature differential during stress-relieving was somewhat low at this end, and sufficient stress remained to allow the formation of a crack. This steel was very susceptible to cracking, and the critical stress level was presumably quite low. The benefit of the stress-relieving treatment is amply demonstrated by the ratio of 101 in. of cracking to 2.4 in. of cracking under severe conditions of corrosion.

DISCUSSION OF LABORATORY TESTS

The results of the laboratory tests are summarized in the following table:

Steel no.	*Yield point, psi*	*% C*	*Specimen condition*	*Exposure, hr*	*Cracking, in.*
12	36,300	0.24	As-welded	455	0
12	36,300	0.24	LTSR*	455	0
16	32,700	0.16	As-welded	200	15.4
16	32,700	0.16	LTSR	200	0
3	48,100	0.082	As-welded	70½	101.0
3	48,100	0.082	LTSR	70½	2.4

* LTSR = Low-temperature stress-relieved.

With regard to steel composition, Pearson and Parkins[4] noted that cracking susceptibility increased as the carbon content decreased. The above results show the same indication: a 0.24% carbon steel did not crack, a 0.16% carbon steel was cracked and a 0.082% carbon steel was most susceptible, even though fully killed. It is also probable that the specimen from Steel No. 3 contained a higher level of residual stress, because of the relatively higher yield point.

These tests showed that residual welding stress was sufficiently high to cause stress-corrosion cracking under some conditions, and that low-temperature stress-relieving was effective in reducing cracking.

SUPPLEMENTARY TESTS

In order to supplement the laboratory tests, four specimens were immersed in a large nitrate storage tank for a period of 10 months. The tank contained 83 to 85% ammonium nitrate at a temperature of 165 to 170° F. These specimens were prepared from Steel No. 7 and consisted of two submerged arc butt welds, each measuring ½ by 24 by 30 in., and two specimens simulating welded clips which are used for handling heavy plates. The latter specimens consisted of a ½- by ¾- by 3-in. steel bar joined to the center of a ½- by 18- by 24-in. plate by means of a coated electrode (E-6010) fillet weld on one side of the bar. One specimen of each type was low-temperature stress-relieved. The simulated clip was stress-relieved by using standard conditions for ½ in. thick plate and extending the heated zone 4 in. beyond each end of the weld.

Fig. 8 As-welded specimen, Steel No. 7, after a 10-month exposure to ammonium nitrate solution. Extent of cracking equaled 24.75 in.

After the 10-month exposure period, the specimens were removed from the tank and examined. Figure 8 shows the top of the as-welded butt weld after the weld area had been buffed to remove the scale. Severe cracking took place, and one of the major cracks can be readily detected. The plate contained seven separate cracks ranging from 1.0 to 9.5 in. in length, and the total length of cracking was 24.75 in. Figure 9 is a radiograph print of a section containing five of the cracks. These cracks were all predominantly intergranular and were similar in appearance to those previously shown. All cracks extended completely through the plate.

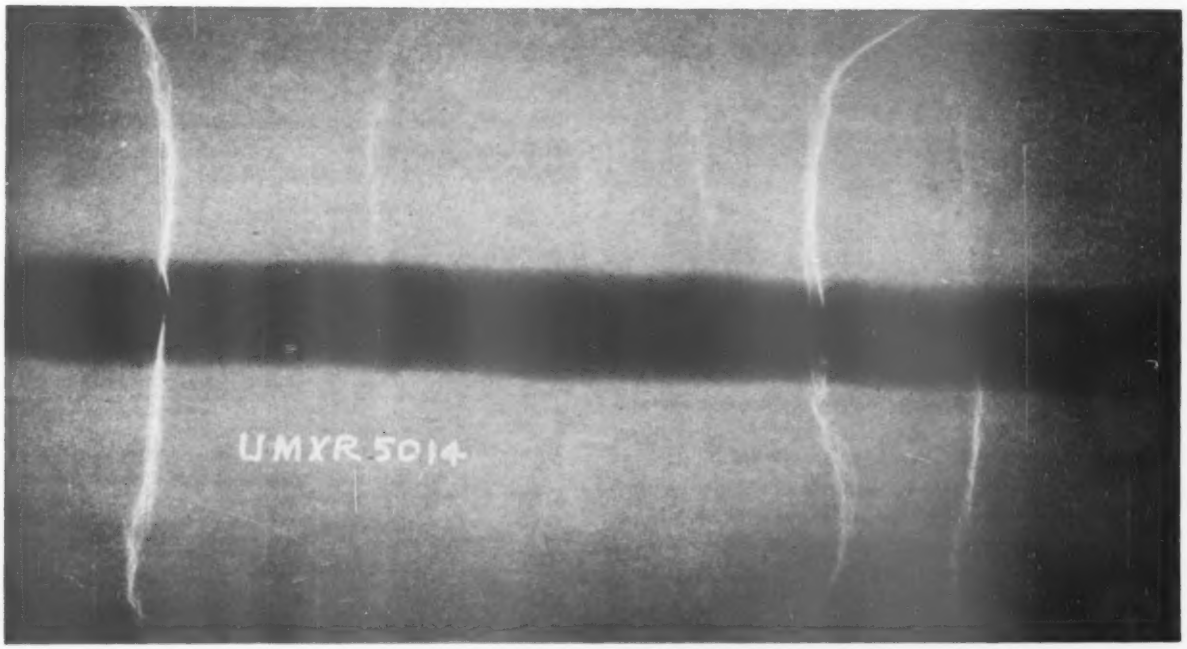

Fig. 9 Radiograph print of as-welded specimen, Steel No. 7, showing area of severe cracking

Fig. 10 Low-temperature stress-relieved specimen, Steel No. 7, after a 10-month exposure to ammonium nitrate solution. One crack, 0.75 in. long, in designated area

Fig. 11 Simulated clip weld, as-welded, after a 10-month exposure to ammonium nitrate solution. Extent of cracking equaled 8.0 in.

Figure 10 shows the top of the low-temperature stress-relieved plate after buffing. Although no cracks are readily apparent, one small crack was present, as indicated by the arrow near the left end of the plate. This crack was $^3/_4$ in. long. As was the case with Steel No. 3, the crack apparently occurred in the area where the temperature differential during stress-relieving was somewhat low. The reduction in cracking from 24.75 to 0.75 in. clearly shows the benefit of stress-relieving.

A photograph of the simulated clip weld, tested in the as-welded condition, is shown in Fig. 11. A small crack was visible near the end of the weld in the area designated by the arrow. Radiographic examination of the weld area, including the section beneath the steel bar, revealed a total length of cracking equal to 8.0 inches. One of the radiographs is reproduced in Fig. 12.

Fig. 12 Radiograph print of as-welded simulated clip weld, showing stress-corrosion cracks around weld.

The companion stress-relieved weld was examined both visually and radiographically, and no cracks were detected.

These tests confirmed the results of the laboratory tests showing that low-temperature stress-relieving was effective in protecting welded plates from stress-corrosion cracking.

CONCLUSIONS

The following conclusions appear to be warranted:

1. Stress-corrosion cracking was produced in some steels in the as-welded condition by exposure to certain nitrate solutions under proper conditions of temperature and time.

2. The severity of stress-corrosion cracking increased as the carbon content decreased, and both rimmed and killed steels were susceptible.

3. Controlled low-temperature stress-relieving was effective in reducing the susceptibility of welded plates to stress-corrosion cracking.

ACKNOWLEDGMENT

The author is indebted to the late T. W. Greene and to numerous members of the staff of the Metals Research Laboratories for helpful advice and constructive criticism, freely given. Acknowledgment is also due to the Spencer Chemical Co. for providing test facilities for some of the specimens.

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Initiation and Propagation of Brittle Fracture in Structural Steels

Discussion by B. Persson

With reference to the discussion by G. M. Boyd, which I agree to in the main, I want to make a few remarks as follows:

The Pellini explosion test seems to mean a more severe treatment than that occurring in service conditions in ships. To support this statement I want to refer to Fig. 10 in the paper under discussion which is related to rimmed steels and Fig. 8 in the NBS investigation which may as well be considered as related to rimmed steels. According to the first one an energy level of about 34 ft-lb is needed to stop cracks, in the latter only about 19 ft-lb. Maybe that the more severe treatment in the explosion test is responsible for the fact, that the impact test values corresponding to the fracture transition as per the explosion test are higher for killed steels than for rimmed steels.

In spite of the imperfections of the impact tests, it seems to me possible to use them, together with other tests, analysis requirements and requirements of fabrication methods, as classification basis for steel qualities in order to get suitable steels for different purposes. Which impact test of all is most suitable for this purpose is another question which falls outside the scope of this discussion.

B. Persson is connected with the Eriksbergs Mek. Verkstads Aktiebolag, Gothenburg, Sweden.

Paper by Peter P. Puzak, Earl W. Eschbacher and William S. Pellini was published in THE WELDING JOURNAL, **31** (12), Research Suppl., 561-s to 581-s (1952). Discussion by G. M. Boyd published in THE WELDING JOURNAL, **33** (1), Research Suppl., 30-s (1954).

Authors' Reply

The authors wish to thank G. M. Boyd and B. Persson for the several interesting discussions. Mr. Persson points out that our Fig. 10 for rimmed steels indicates that 34 ft-lb is required to stop crack propagation while 19 ft-lb at the service temperature was the maximum value found by the National Bureau of Standards investigation for plates which fractured through in service. Now, Fig. 10 gives results for 7 rimmed steels and the values for crack stopping are as follows:

Table 1

Steel	*NRL crack-starter explosion tests, ft-lb for stopping 0.010- to 0.020-in. shear lip*
29	27–34
30	24–29
31	16–19
32	19–24
33	8–11
34	16–20
35	14–18
Avg	18–22

The National Bureau of Standards data for "through" plates record a maximum of 19 ft-lb; the range is 4 to 19 and the average about 10 ft-lb. In interpreting these data it should be recognized that the low values simply mean that poor plates were in the way of fracture; the important fact which Mr. Persson recognizes is that anything above 19 ft-lb automatically made the plates fall into the "end" or stop variety. It was only for "end" plates that the National Bureau of Standards found values in excess of 19 ft-lb. Now, it seems to us that the explosion test is in very good agreement indeed for it indicates without exception that crack stopping will occur whenever values in the range of 20 to 30 are encountered and for several steels at values slightly below 20 ft-lb. The 34 ft-lb mentioned by Mr. Persson is simply the maximum value for a range (27 to 34) within which crack stopping is indicated for this steel.

The value of the crack-starter test is demonstrated by the fact that we are here discussing the fact that one (and only one) rimmed steel indicated easy crack propagation to 27 ft-lb i.e., 8 ft-lb above the maximum of 19 ft-lb shown by the National Bureau of Standards. This is cutting things pretty close.

Since the original paper we have conducted further tests on other ship plate steels including ship fracture plates. We no longer measure the shear lip (since this is a tedious operation) for it has been determined that the same answer is obtained by taking the transition as the change from complete fracture of the test plate to partial fracture, see Table 2. This always occurs in a 20° F step; for example at 40° F we may have complete fracture through "*T*" the lightly loaded edge regions of the bulge specimen (propagation easy) and at 60° F only the center part of the bulge shows cracking "*S*" (propagation difficult). The tests are conducted in 20° F steps hence the 20° F range which marks the change stated above serves nicely to define the transition from easy to difficult crack propagation (*T* to *S*).

Table 2

Steel	*NRL crack-starter explosion tests, ft-lb for stopping* *T*	*S*
29	27	41
30	23	31
31	11	17
32	19	26
33	9	13
34	11	16
35	11	16
Avg	16	23

The drop weight test serves to indicate the temperature below which the *initiation* of fracture is easy—as denoted by fracture on the application of a very small amount of deformation (2 deg of bend after brittle weld is cracked). These data for all of the ship plate steels tested may be summarized as follows:

	Ship service	*Crack-starter test*
Fracture initiation (drop weight vs. "source" data)	Not above 11.4 ft-lb temp in any case	Not above 10 ft-lb in drop weight test
Propagation permitted (through *T* test vs. "through" data)	Not above 19 ft-lb in any case	Not above 27 ft-lb in any case. In most cases 15 to 20 ft-lb is the limit
Propagation stopped (stop *S* test vs. "end" data)	In some cases by values as low as 5 ft-lb; however, this probably represents stopping due to low stress level. Values above 20 ft-lb always resulted in stopping	Never below 13 ft-lb temp—in most cases values in excess of 20 ft-lb were required to produce stoppage

This is very good agreement with service and certainly indicates that the explosion test is not more severe than service. Actually, the explosion test provides a provocation to fracture if the steel is susceptible—if not, fracture does not result. It is unfortunate but true that the correlation with Charpy V energy which obviously holds for both the National Bureau of Standards data and the Naval Research Laboratory crack-starter test data for rimmed and semikilled steels does not hold for fully killed steels. There are no service data such as the National Bureau of Standards type for fully killed steels; however, the fact that the crack-starter data agrees with the National Bureau of Standards data on the ship steels but shows something different for the fully killed steels should indicate caution in the extension of the National Bureau of Standards type correlation to these other steels.

We are entirely in agreement that the best hope for control and classification of steels is in the application of such tests as the Charpy V.

Army First Pass Groove Weld Crack Susceptibility Test

This test is predicated on the necessity of producing satisfactory crack-free first pass welds and bringing about the welding of first pass welds to a scientific level

by Z. J. Fabrykowski, S. Goodman, and B. A. Schevo

INTRODUCTION

Basis of Need for Test

PRELIMINARY welding tests are necessary for successful fabrication of various welded structures. Welding tests promote better understanding of the mechanism of producing first pass welds in groove-type joints. Difficulties encountered in preparing procedure qualification plates and the painful experiences encountered in production point to the need of a dependable welding test. The welding of material which may be crack sensitive or use of untried or uncertain welding procedures magnify the need for such a test.

History of Development

1. The Army First Pass Groove Weld Crack Susceptibility Test is predicated on the necessity of:

(*a*) Producing satisfactory crack-free first pass welds.

(*b*) Bringing about the welding of first pass welds to a scientific level rather than an art dependency.

This test is related to groove welds as they exist in production weldments, and based on the fact that first pass welds are more difficult welds to produce successfully. The test plate was designed to contain full restraint and developed with the thought in mind that it is safer to obtain test conditions of equal or greater joint severity than that existing in production weldments and that it is simpler to relax stringent controls than to increase them.

Z. J. Fabrykowski, S. Goodman, and B. A. Schevo are with the Detroit Arsenal, Ordnance Corps, Center Line, Mich.

Presented at the National Fall Meeting, AWS, held in Cleveland, Ohio, Oct. 19-23, 1953

2. In developing the tests, the initial idea was to assemble two plates with prepared edges by welding straps on each end of the groove joint. This "I" plate was later modified by replacing the straps with weld blocks. After considerable test experience it was found necessary to change the specimen again to one wherein restraint is provided by preparing a slot in a single plate. Stress analysis and practical experience has demonstrated the test plate provides full restraint transversely throughout the length of the groove joint when:

(*a*) The weld throat thickness is held at a maximum of $^{9}/_{32}$ in.

(*b*) Weld metal ultimate strength is 120,000 psi, max.

(*c*) Plate material is Army armor.

Practical Application of Test

The Detroit Arsenal has used this test to evaluate conditions of various welding factors which constitute a welding procedure and to effectively translate the procedure into production use through the medium of procedure qualification plates reflecting joint design conditions and materials peculiar to the production weldment. This test has also been used for the purpose of evaluating, under a predetermined set of conditions, the susceptibility of electrode deposits to cracking and the effect of various moisture contents in electrode coatings on weld deposits. The performance of various types of ferritic electrodes, such as nickel-moly-vanadium and moly-manganese electrodes, and cracking location differences which exist when applied in this test, can be understood and appreciated before application to production. The Army First Pass Groove Weld Crack Susceptibility Test has proved itself through this testing medium. It has been demonstrated that a large number of identical qualification plates, having complete joint restraint, can be reproduced and welded satisfactory. This test is a valuable aid for fabrication of completed groove welds. Among other things, it is

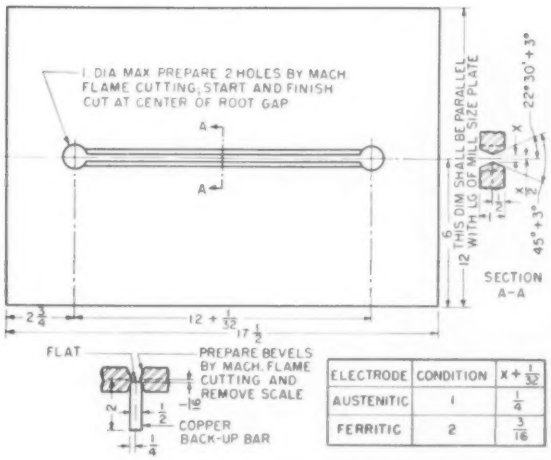
1. DIA MAX PREPARE 2 HOLES BY MACH FLAME CUTTING, START AND FINISH CUT AT CENTER OF ROOT GAP
A
A
THIS DIM SHALL BE PARALLEL WITH LG OF MILL SIZE PLATE
22° 30' + 3°
45° + 3°
SECTION A-A
2 3/4
12 + 1/32
17 1/2
FLAT
PREPARE BEVELS BY MACH. FLAME CUTTING AND REMOVE SCALE
COPPER BACK-UP BAR
ELECTRODE | CONDITION | X + 1/32
AUSTENITIC | 1 | 1/4
FERRITIC | 2 | 3/16

Fig. 1 The test specimen

informative in indicating (1) threshold cracking temperatures, (2) need for preheat and (3) interpass temperature control; for deposition of satisfactory first pass welds.

TEST PROCEDURE

The Specimens

The specimens, Figs. 1 and 10, may be easily prepared entirely by flame cutting. The plate is first cut to size and location of the end holes marked as shown in Fig. 2. After flame piercing and cutting the holes, Fig. 3, the bevels are cut. The bevels may be cut from the top side of the plate. There is no necessity of turning the plate over. Figure 4 shows the flame-cut plate. Cutting scale is removed to insure a clean welding surface.

Welding

Welding is performed manually on a plate in the desired test position. The backing bar is located to protrude into the hole at the beginning of the joint. The arc is established on the backing bar in the hole area, Fig. 5. It is brought into the joint, held there long enough to produce fusion and build-up of root bead thickness, and the electrode consumed until a 3-in. stub remains. Rate of travel of the arc should be such to produce a uniform throat thickness throughout the length of the joint. After each electrode is deposited, the slag is removed from both surfaces of the weld and

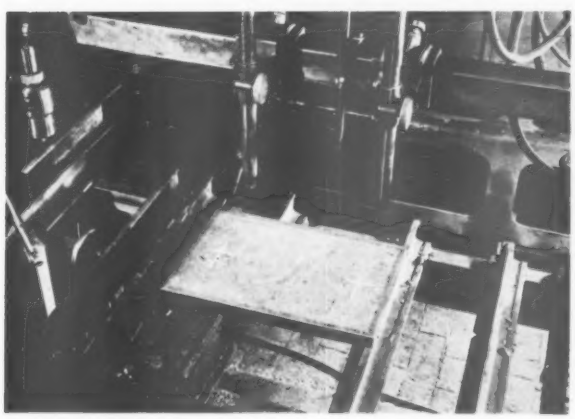

Fig. 2 Crack susceptibility plate. Virgin plate

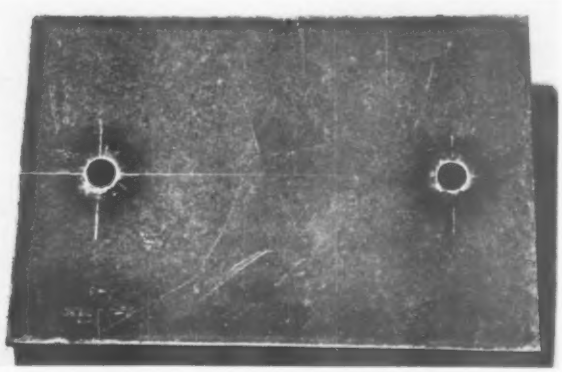

Fig. 3 Crack susceptibility plate with holes pierced

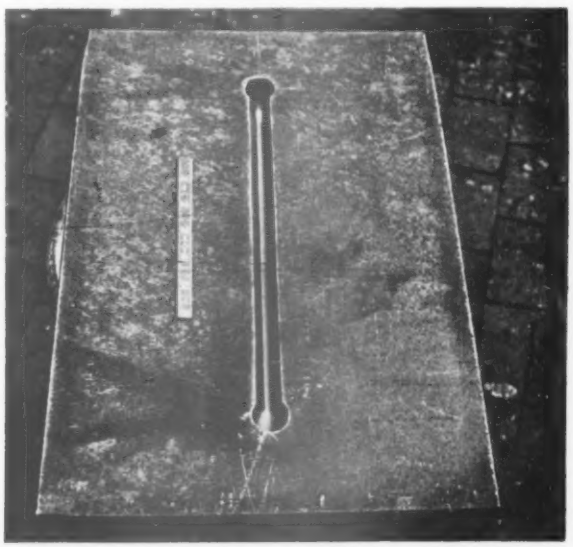

Fig. 4 First pass crack susceptibility test plate

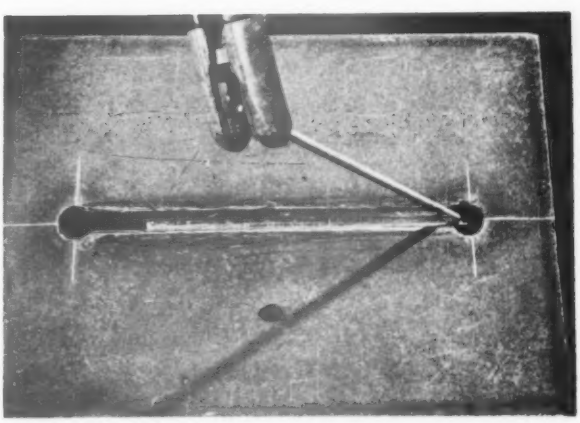

Fig. 5 Crack susceptibility plate. Electrode in position before striking arc

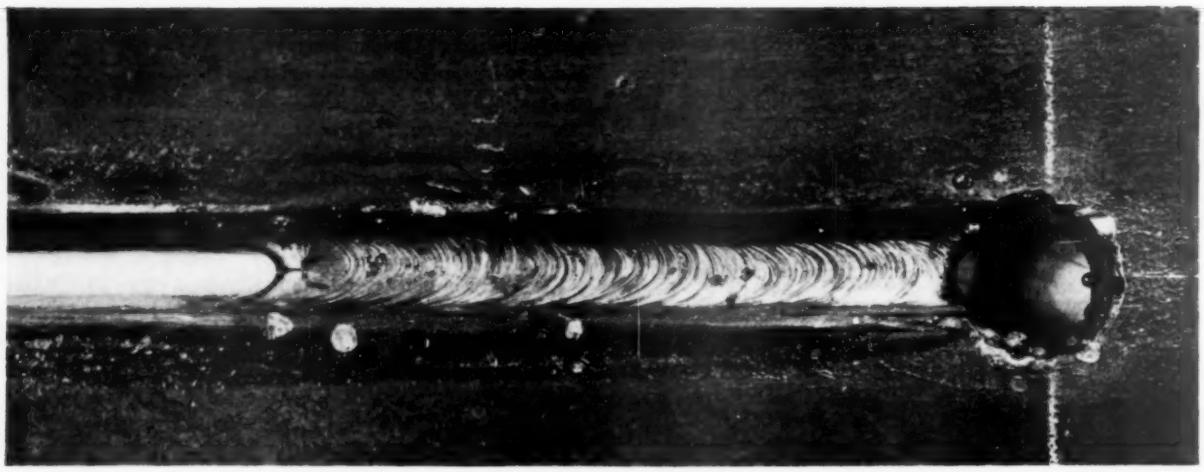

Fig. 6 First electrode with crater crack

the crater ground and feathered. Figure 6 shows the welding crater-crack before grinding. The deposit is visually examined for cracks. If cracks are not present, welding is continued and the first pass weld completed. At the termination of the weld, which is approximately $^1/_2$ in. before the end of the joint groove, the arc is snapped out while in a forward motion without filling the crater. The crater is left in the as-welded condition,

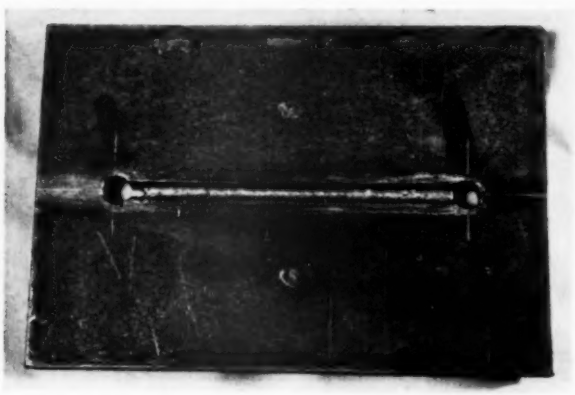

Fig. 7 Plate with root pass complete (top side)

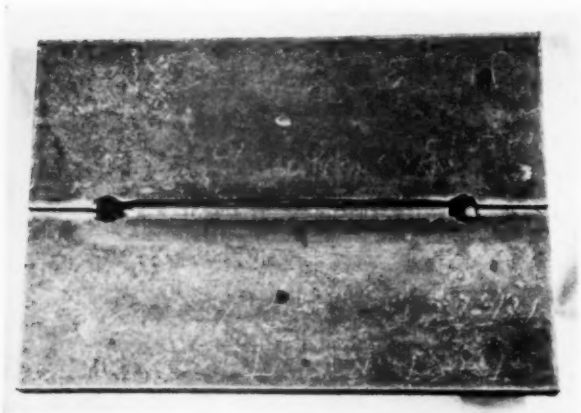

Fig. 8 Plate with root pass complete (bottom side) after stress relaxing

A 200F Preheat

B 185 F Preheat

Fig. 9 Single pass root bead. Deposited with Brand 4 electrodes. Etchant: 10% ammonium persulfate. Magnification, ×3

Table 1—Test Results

Plate	*Preheat, ° F*	*Plate temperature after welding, ° F*	*Maximum plate temp., ° F*	*Temperature at time of crack, ° F*	*Cracks*
			Brand 1		
1-1	200	280	300	..	None
1-2	185	250	270	..	None
1-3	175	240	270	..	None
1-4	160	240	265	..	None
1-5	150	220	250	170	1W, 4 1/2 HAZ, 4 1/2 HAZ*
1-6	150	220	245	130	1W, 5 HAZ
			Brand 2		
2-1	200	280	300	..	None
2-2	185	260	280	..	None
2-3	175	250	270	..	None
2-4	160	250	260	..	None
2-5	150	210	230	190	1W, 10 HAZ
2-6	150	210	230	185	1W, 10 HAZ
			Brand 3		
3-1	200	280	300	..	None
3-2	185	260	280	..	None
3-3	175	250	270	..	None
3-4	160	240	260	..	None
3-5	150	205	230	190	1W, 3 1/8 HAZ, 1 1/8 HAZ, 1 1/4 HAZ
3-6	150	210	240	185	1W, 4 HAZ, 4 HAZ
			Brand 4		
4-1	200	260	300	..	None
4-2	185	250	290	180	4 HAZ, 1W, 3 HAZ, 3 HAZ
4-3	185	260	290	130	3 HAZ
			Brand 5		
5-1	200	280	300	..	None
5-2	185	270	290	..	None
5-3	175	270	270	..	None
5-4	160	220	240	..	None
5-5	150	210	230	185	1W, 9 HAZ
5-6	150	210	230	185	1W, 9 HAZ

* W—Indicates a center-of-weld crack; HAZ—indicates a heat-affected zone crack.

except for slag removal, to develop a crack sensitizer and cause the test to be more rigid by simulating normal use of electrodes.

EVALUATION OF TEST

The test specimen weldment is next carefully observed for appearances of cracks. Temperature readings are taken on ground spots, Fig. 7, 3 in. from the weld at its mid-point. If no cracks occur within 15 min after the plate reaches room temperature the restraint is relaxed by flame cutting the plate from the holes to the outside ends, as shown in Fig. 8. Should cracks occur before the plate reaches room temperature, the particular temperature at which cracks occur is recorded. The cold plate, room temperature, is further examined by magnetic particle inspection for ferritic deposits, or dye penetrant inspection for austenitic deposits. If cracks

Table 2—One-Inch Test Plate Results

Preheat, ° F	*Cracking temperature*	*Location and length of cracks*	*Plate temperature, ° F after welding*
		Special (Mn-Mo)	
180	110	HAZ-3	250
190	125	HAZ-3	250
200	100	HAZ-3	285
210	100	HAZ-2	300
250	...	None	320
		Gr 230 (Ni-Mo-V)	
75–80	...	None	185
		NRC-2A (Mn-Mo)	
160	140	HAZ-3, HAZ-2	245
175	120	HAZ-3	265
180	115	HAZ-3	245
190	..	None	245

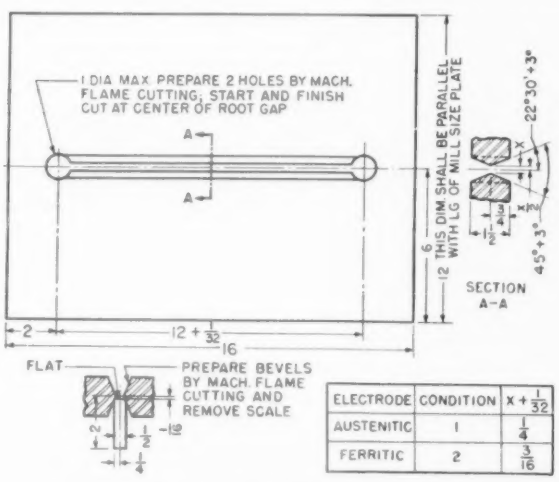

Fig. 10 The test specimen

Table 3—One and One-Half-Inch Test Plate Results*

Electrode group†	*Plate temperature after welding,* ° *F*	*Temperature at which crack occurred,* ° *F*	*Cracks*‡
A 1¼-1	155	...	None (1/4)
A 1¼-1	160	...	None (17/64)
A 1¼-3	150	...	None (1/4)
B 1¼-1	140	120	3½ HAZ (9/32)
B 1¼-2	150	110	4W (1/4), 2 HAZ (9/32), 2W (1/4)
B 1¼-3	155	115	9 HAZ (9/32)
C 1¼-1	150	120	5W (1/4), 2½ HAZ (17/64)
C 1¼-2	150	120	5W (1/4), 2 HAZ (1/4)
C 1¼-3	150	80	3½ HAZ (9/32)
D 1¼-1	160	135	9 HAZ (9/32)
D 1¼-2	145	135	9 HAZ (1/4)
D 1¼-3	150	135	9 HAZ (9/32)
E 1¼-1	135	125	5 HAZ (9/32), 4 HAZ (9/32)
E 1¼-2	150	145	9 HAZ (1/4)
E 1¼-3	145	135	9 HAZ (9/32)

* Relative humidity—97% at 46° F (outdoor temperature).
† Gr 230 electrodes—varying moisture contents.
‡ Explanation: 4W (1/4)—4-in. crack in center of weld of 1/4-in. throat; 9 HAZ (1/4)—9-in. crack in heat-affected zone of deposit with 1/4-in. throat.

are not present three cross sections are removed from areas at right angles to the weld joint within 2 hr after the plate has reached room temperature. These samples, representative of the entire length of the weld deposit, are subjected to either magnetic or dye inspection. A satisfactory test is realized if no crack is revealed in the cross sections. Existence of crater-cracks less than 1/2 in. long in the mean throat thickness is permitted and does not constitute a weld failure.

UTILIZATION OF TESTS

An illustration of how this test has been applied is shown in Fig. 9, which illustrates cross sections of ferritic welds in 1-in. plate. Table 1 lists the results of tests conducted for determination of lowest preheat temperatures for deposition of five different brands of ferritic electrodes.

Another investigation, Table 2, concerned the lowest preheat temperature at which a particular electrode could be used for depositing sound welds under conditions of restraint.

The Army First Pass Groove Weld Crack Susceptibility Test is used at the Detroit Arsenal for testing of austenitic electrodes used for production welding of ballistic joints. Electrodes are tested according to core wire heat numbers and coating process numbers.

This test has also been applied for determining the effect, on welding, of moisture in the coating of the low hydrogen type electrodes. Electrodes of varying moisture contents were deposited in test plates at room temperature. See Table 3.

The 1-in. test plates produced a different rate of heat dissipation which did not permit evaluation of the effect of electrode water content on the soundness of weld metal deposited. Employment of 1½-in. test plates, however, indicated a trend. A decrease in water content of an electrode coating lowered the temperature at which weld metal, deposited by that electrode, produced a crack.

DISCUSSION

The Army First Pass Groove Weld Crack Susceptibility Test Plates shown in Figs. 1 and 10 may be made by methods which represent normal joint preparation. The root gaps illustrated are those the Detroit Arsenal uses for 3/16-in. diam austenitic and ferritic electrodes. Root gaps are related to electrode sizes. Production fabrication factors, such as angle of bevel, welding current, method of weld backing, etc., must be considered. The material from which specimens are to be prepared should be that which is currently used for fabrication at the particular installation conducting the test.

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Effects of Alloying Elements on the Weldability of Titanium Sheet

If an alloy of titanium is brittle in the as-welded state, preheating is not likely to improve ductility whereas a postheat treatment can generally be found which will effectively restore a large measure of ductility

by H. M. Meyer and W. Rostoker

Abstract

The reactions of 11 alloys, selected from three categories of titanium base alloys, to arc welding have been studied. The program included the influence of pre- and postheat treatments on the mechanical properties of welded specimens. Mechanical properties measured were bend ductility, tensile strength and elongation, and hardness. Microstructures were examined extensively with a view to recording their relationships to mechanical behavior. A number of alloys are extremely brittle in the as-welded state. Preheat treatment did not generally improve the ductility of the as-welded state. In almost every case, a large measure of ductility could be restored by postheat treatment. No single postheat treatment procedure was found applicable to all alloys.

I. INTRODUCTION

PROBLEMS in welding of titanium and its alloys may be classified in terms of welding technology—including the mode of heat generation, electrode conditions, mechanics of feed, the means of preventing contamination from atmospheric elements—or in terms of physical metallurgy of weldments—involving the correlations between pre- and postheat treatments, mechanical properties and microstructures associated with the weld metal and heat-affected zones.

This paper deals with the second topic. The process selected was inert-gas, nonconsumable electrode arc welding. A selection was made representative of characteristic alloy systems and characteristic tendencies toward transformation during cooling. Alloys were prepared by double melting in argon-arc melting units and subsequently forged and rolled to sheet form.

Binary alloys based on titanium can be classified into three types of phase equilibria systems:

1. *Stabilized alpha systems.* The alpha phase is stabilized to temperatures above the allotropic transformation temperature with increasing alloy content. The binary systems Ti-Al, -O, -N, -C belong to this group.

2. *Stabilized beta systems.* The beta phase is stabilized to temperatures below the allotropic transformation temperature with increasing alloy content. The binary systems Ti-Mo, -V, -Ta, -Cb belong to this group.

3. *Eutectoid systems.* This type is essentially the same as (2) except that the stabilization of beta is interrupted by a eutectoid transformation to alpha and an intermediate phase. The binary systems Ti-Cr, -Fe, -Mn, -Cu, -W, -Si belong to this group.

The systems Ti-Zr and Ti-Hf properly belong in a separate group because both solute elements have the same allotropy as titanium and the allotropes are completely miscible.

For this study, 11 compositions were chosen from the systems Ti-Al, Ti-Mo, Ti-Cr.

The use of heat treatments to enhance the mechanical properties of weldments can be categorized by the terms preheat treatment and postheat treatment. The ideal welding alloy would be one which, heat treated by the manufacturer, would give adequate ductility and strength to the wrought metal and would not subsequently embrittle as the result of a welding operation during the assembly of some manufactured product at some other plant. It was realized from the beginning that such possibility was limited to the special cases of:

1. Very low alloy content where mechanical properties are relatively unaffected by any thermal history.

2. Very high alloy content where the transformation rates of beta phase are too sluggish and the heating and cooling cycles involved in welding would be too rapid to initiate any transformations.

A parallel exists in ferrous metallurgy of low-carbon, mild steels on the one hand and austenitic steels on the other hand.

The role of preheat treatment can be twofold. Obviously the initial sheet material is required in ductile form. To this extent pretreatment after final rolling is necessary but is not within the province of welding research. There remains the possibility that the nature of weld embrittlement differs with the kind of pretreatment. If that situation were real, a true interdependence between pre- and posttreatments would exist. Experiments were conducted to investigate whether such an interrelationship existed. Apart from these possibilities, it is to be expected that for alloys with mechanical properties sensitive to thermal history, the posttreatment stage would be vital to the successful manufacture of ductile weldments. Therefore, the use of postheat treatments is reserved for the instances that the as-welded state has undesirable mechanical properties which cannot be altered effectively by preheat treatment.

The origins of embrittlement in titanium alloys may be threefold:

1. The content of interstitials (oxygen, nitrogen, carbon, hydrogen). Each of these elements can have disastrous effects on weld ductility. Therefore, the successful development of useful alloys demands the minimized and controlled occurrence of these elements. In the work reported here, every effort has been made to use pure materials and to prevent increased contamination during alloy preparation and experimentation.

2. The dispersion of a second phase in a matrix phase. In a recent paper,[1] it

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was demonstrated that decrease in ductility could be correlated with increasing fineness in the alpha precipitate.

3. Precipitation effects. As will be discussed below, certain ranges of composition exist which on normal quenching from the beta field are very brittle. These same alloys can be rendered ductile by very rigorous quenching. In both cases, the microstructures appear to be retained beta.

Origins of embrittlement (2) and (3) can probably occur simultaneously in a two-phase structure.

II. PREPARATION, TREATMENT AND TESTING OF ALLOY SHEET

A. Materials

Melts were made from a single lot of magnesium-reduced sponge, supplied by the Titanium Corporation of America, with an average hardness of 143 BHN. Molybdenum additions of less than 10% were in the form of 0.003-in. sheet of 99.9% purity, supplied by the Fansteel Metallurgical Corp. Higher additions required a preliminary melting of small 150-g heats of master alloy.

Normal electrolytic chromium contains about 0.5% O, largely tied up as oxides. Most of this oxygen is dissolved into the melt and can cause an inordinate increase of the interstitials at higher chromium contents. Anticipating trouble of this kind, a high purity chromium (Bureau of Mines, Albany, Ore.) was acquired for the Ti-Cr alloys. A lot analysis follows:

Analysis of Bureau of Mines Chromium

Cr = 99.9+%	C = 0.033%
Fe = 0.02%	Si $\leqslant$ 0.01%
N = 0.001%	S $\leqslant$ 0.01%
O $\cong$ 500 ppm	H $\cong$ 50 ppm

Aluminum, 99.99+% pure, from the Aluminum Company of America was added directly in cut sheet form.

B. Melting Practice

Alloys were prepared by a double melting procedure designed to provide complete solution of the alloying elements. The first melting was performed in a nonconsumable electrode, water-cooled crucible, arc-melting furnace, feeding multiple 200-g weighed charges. Ingots so cast were forged to $^1/_2$-in. diam rods; the rods were cleaned of adherent oxide scale by shotblasting and pickling and, in later stages of the study, by centerless grinding, before their use in a consumable electrode, arc-melting furnace. Ingots were generally of the order of 4 to 8 lb, although some 200-g pancake ingots were made in the exploratory stages of this study. The final ingot was cleaned to remove surface defects, and then forged to $^1/_2$-in. thick plates for subsequent rolling. Forging temperatures were of the order of 1600–2000° F.

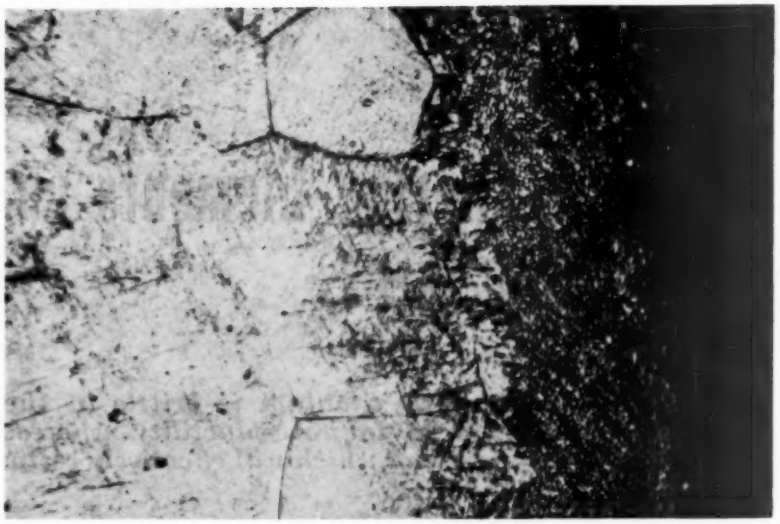

Fig. 1 7% Cr alloy showing surface contamination by oxygen and nitrogen. This is evident from the advanced state of transformation at the surface compared with the interior. × 250

C. Rolling Practice

For a period of time, hot rolling was conducted on a small mill with 4$^1/_4$-in. diam rolls. With such a mill, it is not possible to make reductions of more than 0.005 in. per pass. This necessitated frequent reheating, especially near the finished gages. The resultant sheet often gave poor bend ductilities even under conditions of heat treatment which prior experience indicated should provide excellent bend properties. Examination of a number of these specimens provide metallographic evidence of higher concentrations of interstitial elements at the surface of the sheet.

It has been demonstrated[2] that with increasing oxygen content, rates of transformation are accelerated. Accordingly, the presence of excess oxygen on the sheet surface can be deduced from the advanced state of transformation which that area of specimen exhibits, compared with the interior. Figure 1 illustrates this effect.

It is suggested that the nature of anomalously brittle sheet materials can be investigated by this method. The procedure is as follows: From prior knowledge of the transformation rates of good quality material, one isothermally transforms a specimen of the questionable sheet under conditions which will induce only the beginning of transformation in uncontaminated metal. Microexamination of the sheet cross section will then show the surface to be in an advanced state of transformation compared with the interior if contamination during hot rolling has occurred. Precautions are necessary to prevent contamination during solution treatment of the specimen prior to the isothermal transformation.

Having demonstrated that the production of good quality sheet by hot rolling is prejudiced by too frequent reheating, the use of a 10-in. rolling mill was adopted, with which large reductions per pass could be effected and the time of exposure to oxidizing conditions at elevated temperatures could be shortened. The quality of the sheet was correspondingly improved. The final sheet thickness was $^1/_{16}$ in.

D. Welding Practice

The arc welding machine selected was a Lincoln Shield-Arc Welder of 200 amp capacity. This power supply feeds an inert gas tungsten electrode arc-welding setup, which uses an oxy-acetylene cutting machine as the automatic travel part.

The welding circuit includes a high-frequency exciter. When operated with a condenser (16 microfared, 600 v, dc capacitor) across the leads to the welding station, the welding circuit automatically starts the arc as the electrode passes over the sheet.

High-purity helium (Bureau of Mines, Amarillo, Tex.) was selected as the inert gas. Helium proved by test to be superior to argon in protective ability. A model H35-A Manual Heliweld Holder (Air Reduction Co., Inc.) was built into the assembly.

A copper chill-block fixture with quick-acting toggle clamps was designed for holding the specimens (see Fig. 2). The copper backup plates, upon which the specimens are held, are separated by a center piece which has a slot $^3/_8$ by 5$^1/_2$ in. Helium is introduced in this slot during

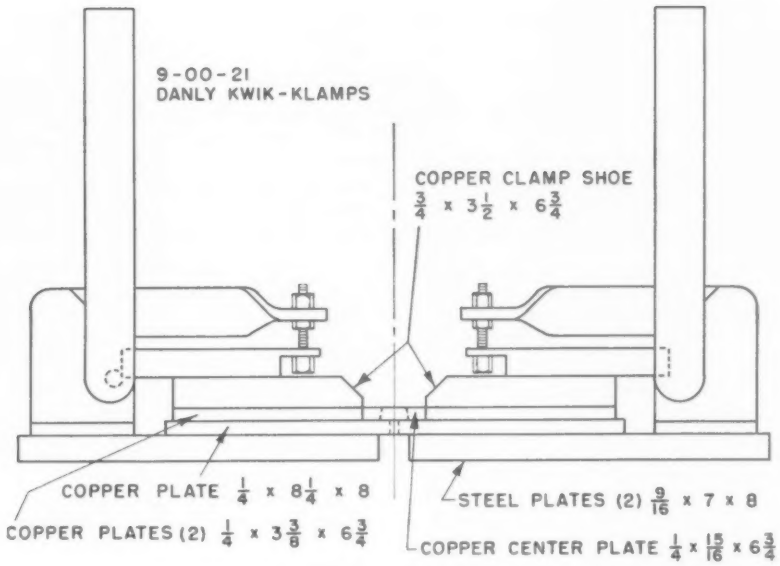
9-00-21
DANLY KWIK-KLAMPS
COPPER CLAMP SHOE
$\frac{3}{4}$ x $3\frac{1}{2}$ x $6\frac{3}{4}$
COPPER PLATE $\frac{1}{4}$ x $8\frac{1}{4}$ x 8
COPPER PLATES (2) $\frac{1}{4}$ x $3\frac{3}{8}$ x $6\frac{3}{4}$
STEEL PLATES (2) $\frac{9}{16}$ x 7 x 8
COPPER CENTER PLATE $\frac{1}{4}$ x $\frac{15}{16}$ x $6\frac{3}{4}$

Fig. 2 Diagram of welding fixture

the welding operation to shield the underside of the joint. The upper side is protected by a separate helium flow and a hood. The hood is mounted on the torch nozzle and keeps a blanket of helium over the sheet while it is at welding temperature and during cooling.

Inert gas flow to both top and underside of the weld was 54 cfh.

E. Heat Treatment Practice

Weld specimens had the dimensions $5^1/_2$ by $2^3/_4$ in. Specimens for mechanical testing were cut with an abrasive cut-off wheel in a direction normal to the weld bead. The use of a cut-off wheel, while more time consuming, was necessary because of the brittleness of many alloys in the as-welded state.

The test pieces were solution treated in a retort, using a protective helium atmosphere. The arrangement was such that the specimens could be withdrawn from the retort and quenched without appreciable loss in temperature during transference. Isothermal transformations were conducted in a lead pot with the specimens completely immersed.

F. SPECIMEN PREPARATION AND TESTING

1. Free-Bend Test

Strips $5^1/_2$ in. long, $^1/_2$ to $^3/_4$ in. wide, with the transverse weld in the middle, were used. After heat treatment and prior to testing, the strips were ground on an abrasive belt until the weld was flush with the sheet stock; its surface was also ground bright and burrs removed.

A free-bend test was adopted because it utilized only one specimen and because it appeared to offer as useful a measure of bend ductility as other, more involved tests. The free-bend test is a severe one because the bending is continued to the complete closing of the jaws upon the folded sheet.

The test is performed by compressing the strips from the ends in a vise. The vise is closed by hand until cracks appear or the sheet snaps. The strips fold where the yield point is lowest if the whole weldment is ductile, as shown in Fig. 3; but when a brittle zone occurs in or near the weld, fracture will occur almost immediately at that point. The bend ductility is measured by the folding distance, i.e., the residual gap between the jaws (minus twice the thickness of the sheet) at the moment of cracking or fracture. The distance between the legs of the specimen after removal from the vise is not indicative of the bend ductility because of the spring back after removal.

2. Tensile Test

Test specimens were milled from $5^1/_2$ by $^3/_4$-in. strips to provide a $^1/_2$-in. test width and a 2-in. test length. The shoulders of the test pieces were milled to $^1/_2$ in. radius. Elongations were measured on 2-in. lengths by means of an extensometer and a prestamped grid on the flat side of the test piece.

III. THE INFLUENCE OF HEAT TREATMENT ON THE MECHANICAL PROPERTIES OF WELDS IN TITANIUM-ALUMINUM ALLOYS

A. Response of Ti-Al Alloys to Heat Treatment

Among the metallic additions to titanium, only aluminum is known to stabilize the alpha modification to higher temperatures. The experimental evidence is that the beta phase cannot be retained even partially below the $\alpha/\alpha + \beta$ boundary by any manner of cooling. Whether the product of transformation of beta by fast cooling is metastable with respect to the same composition annealed in the alpha field is not known, but from the general indifference of mechanical properties to heat treatment this seems to be an academic question.

Structures observed micrographically are single phase but with growth configurations characteristic of prior thermal history. Transformation of the beta phase to alpha develops along crystallographic planes and so the resultant structure has a "serrated" or "basket weave" appearance. The chief apparent variable is the width of the individual alpha plates. On reheating within the alpha field or on combined cold working and annealing in this fashion, the ser-

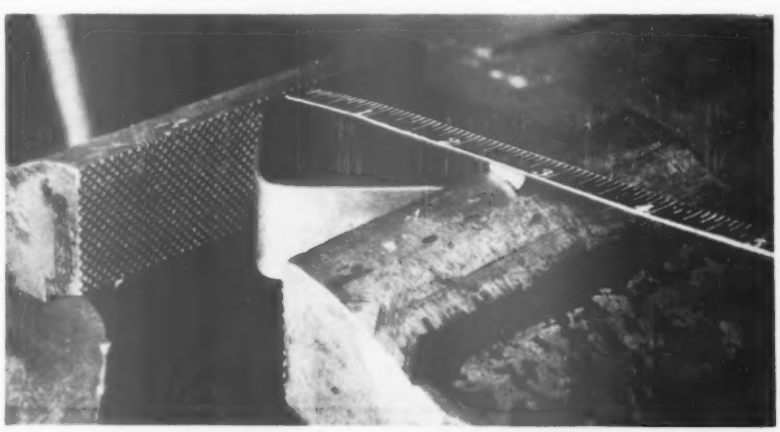

Fig. 3 The free-bend test

rated alpha configurations become modified to an equi-axed grain structure.

The purposes of introducing heat treatments were as follows:

1. To investigate the influence, if any, of the shape of alpha grains.
2. To investigate the influence of prior beta grain size. Since the $(\alpha + \beta)$ phase field is very narrow, all heat treatments were conducted in either the beta or alpha field.

B. Mechanical Properties of Ti-Al Weldments

Three alloys containing 3, 5 and 8% Al, respectively, were studied. Experimentation with the 5% alloy was more detailed than with the other two. Summaries of heat treatments and resultant mechanical properties are given in Tables 1, 2 and 3.

In the 3% Al alloy, welds are quite ductile and moderately strong in the untreated state. Neither pre- nor post treatments appeared to serve a useful purpose. This composition may be regarded as a nonheat treatable welding alloy with the base metal to be provided

Table 1—The Mechanical Properties of Weldments in a 3% Al Alloy

*Heat treatment**	*Free bend folding distance, in.*	*Bend failure†*	*Ultimate tensile strength, psi*	*Tensile elongation, %*	*Tensile failure†*
A. Unwelded:					
1850° F—10 min→WQ	1 3/8	..	115,000	8	..
1450° F—60 min→AC	1/2	..	107,000	17	..
B. Welded and postheat treated:					
As-welded	1/8	HA	121,000	4.5	WM
1850° F—10 min→WQ	3/8	WM	113,000	3	HA
C. Preheat treated and welded:					
1800° F—10 min→AC	1 3/8	WM	79,600	8.5	BM
1450° F—60 min→AC	1/8	HA	105,000	12.5	BM
D. Preheat treated, welded, and postheat treated:					
Pre: 1450° F—60 min→AC– / Post: 1450° F—60 min→AC–	3/16	WM	106,000	12.5	BM

* WQ = water quenched; AC = air cooled; 1800° F is in beta field, 1450° F is in alpha field.
† BM = base metal; HA = heat-affected zone; WM = weld metal.

Table 2—The Mechanical Properties of Weldments in a 5% Al Alloy

*Heat treatment**	*Free bend folding distance, in.*	*Bend failure†*	*Ultimate tensile strength, psi*	*Tensile elongation, %*	*Tensile failure†*
A. Unwelded:					
1350° F—30 min→WQ	11/16	..	133,000	5.5	..
1550° F—30 min→WQ	1/4	..	112,500	17	..
1750° F—30 min→WQ	3/8	..	110,000	11.5	..
1950° F—30 min→WQ	1 5/16	..	126,500	5.5	..
B. Welded and postheat treated:					
As-welded	1/4	WM	132,000	5.5	WM
1350° F—30 min→WQ	3/8	WM	117,500	3	HA
1550° F—30 min→WQ	0	WM	123,000	13.5	WM
1750° F—30 min→WQ	1/4	HA	125,000	12.5	BM
1950° F—30 min→WQ	3/8	WM	83,000	1	HA
C. Preheat treated and welded:					
1350° F—30 min→WQ	1/4	HA	118,000	3.5	BM
1550° F—30 min→WQ	5/16	WM	104,000	1.5	HA
1750° F—30 min→WQ	1/8	HA	116,000	8.5	BM
1950° F—30 min→WQ	3/8	HA	116,000	2.5	BM

* WQ = water quenched; 1950° F is in beta field, 1750° F is in alpha field.
† BM = base metal; HA = heat-affected zone; WM = weld metal.

Table 3—The Mechanical Properties of Weldments in an 8% Al Alloy

*Heat treatment**	*Free bend folding distance, in.*	*Bend failure†*	*Ultimate tensile strength, psi*	*Tensile elongation, %*	*Tensile failure†*
A. Unwelded:					
2100° F—10 min→WQ	4 7/16	Brittle	99,000	1.5	Brittle
1450° F—60 min→AC	5	Brittle	61,500	1.5	Brittle
B. Welded and postheat treated:					
As-welded	4 7/8	WM	147,000	5	WM
2100° F—10 min→WQ	4 15/16	HA	86,000	0.8	BM
C. Preheat treated and welded:					
2100° F—10 min→WQ	5	BM	58,000	1.5	HA
1450° F—60 min→AC	3 7/8	BM		Premature fracture	
D. Preheat treated, welded and postheat treated:					
Pre: 1450° F—60 min→AC– / Post: 1450° F—60 min→AC–	4 15/16	HA	133,000	1.5	HA

* WQ = water quenched; AC = air cooled; 2100° F is in beta field, 1450° F is in alpha field.
† BM = base metal; HA = heat-affected zone; WM = weld metal.

in some state of full or partial anneal depending on strength requirements.

Figures 4 and 5 illustrate equiaxed and serrated structures, respectively. There seems to be no reason to regard either of them as possessing better mechanical properties than the other.

The 5% Al alloy, although investigated in more detail, gave the same evidence of indifference to pre- or postheat treatment. The as-welded state is ductile although the high tensile strength is probably due to the fact that the base metal was in the as-rolled condition. Preheat treatments which soften the base metal also give weaker as-welded tensile strengths. Two instances of poor bend ductility or low tensile strength both occurred when 1950° F anneals were employed. The seemingly random occurrence of these results points to accidental contamination as the likely source of trouble. Of course at 1950° F such troubles are more prone to occur. The general trend of microstructures is identical with the 3% Al alloy. The very coarse-grained structure shown in Fig. 6 proved to have no less bend ductility and tensile strength than did finer-grained structures. Accordingly, grain size *per se* is not likely to be a factor of concern.

The 8% Al alloy proved quite brittle under all conditions of treatment even though small ingots of 100–150 g could be cold rolled as much as 25% reduction without intervening anneal. Because of the rather high forging temperature (2100° F) used on the ingot from which the sheet was rolled, it is suspected that oxygen contamination may have been at least partly responsible for the brittleness.

Hardness plots in as-welded and postheat-treated states were generally uninstructive. It could not be said that any trends really existed because variations over the weld zones did not exceed 25 Vhn which is within the normal accuracy of hardness measurements on titanium.

In summary, the 3 and 5% Al alloys can be classed in the category of nonheat-treatable welding alloys providing tensile strengths dictated by alloy content. The only effects seem to arise from prolonged anneals at temperatures above 1800° F where risks of contamination are more severe. The 8% Al alloy on the basis of preliminary experiments may be either fundamentally brittle or more susceptible to embrittlement by atmospheric contaminants.

IV. THE INFLUENCE OF HEAT TREATMENT ON THE MECHANICAL PROPERTIES OF WELDS IN TITANIUM-CHROMIUM ALLOYS

Four alloys containing 2, 5, 7 and 15% Cr, respectively, have been studied in both the unwelded and welded state under various conditions of pre- and post treatment. The objectives were to establish whether the as-welded state was brittle and if so, whether the brittleness was related to prior structures in the base metal and whether it could be modified by suitable post treatment of the weld and adjacent regions.

A. Response of Ti-Cr Alloys to Heat Treatment

The system Ti-Cr belongs to the group of binary systems including Ti-Mn, Ti-Fe, Ti-Ni and Ti-Cu in which the beta phase is stabilized with increasing alloy content to lower temperature. This part of the phase field terminates in a eutectoid reaction producing alpha and an intermediate phase. The eutectoid reaction is quite sluggish and is not encountered in heat treatments of less than several hours. The chief origins of heat treatability are the precipitation of alpha from supersaturated beta and the behavior of the beta phase on quenching.

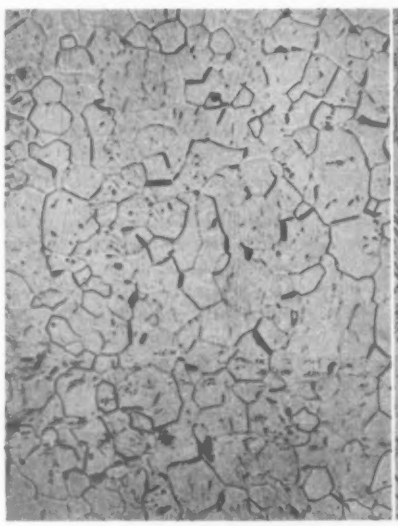

Fig. 4 3% Al alloy

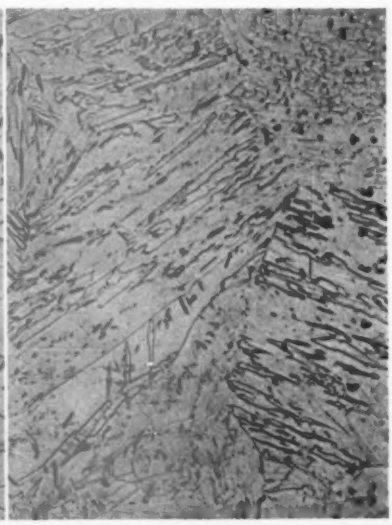

Fig. 5 3% Al alloy

Figure 4. Base metal. Annealing at 1450° F for 60 min has developed a conventional equiaxed alpha structure. The tensile specimen so heat treated broke in this region. Preheat treatment: 1450° F—60 min → AC. Mechanical properties: 105,000 psi—Ultimate tensile strength; ½ in.—folding distance. × 250.

Figure 5. Unwelded. Illustrates typical "serrated" alpha generated by the transformation of beta. When the colonies of alpha platelets appear to be more interlocking or interwoven, present parlance uses the term "basket weave" alpha. Heat treatment: Solution treated—10 min → WQ. Mechanical properties: 115,000 psi—Ultimate tensile strength; 1⅛ in.—folding distance. × 250.

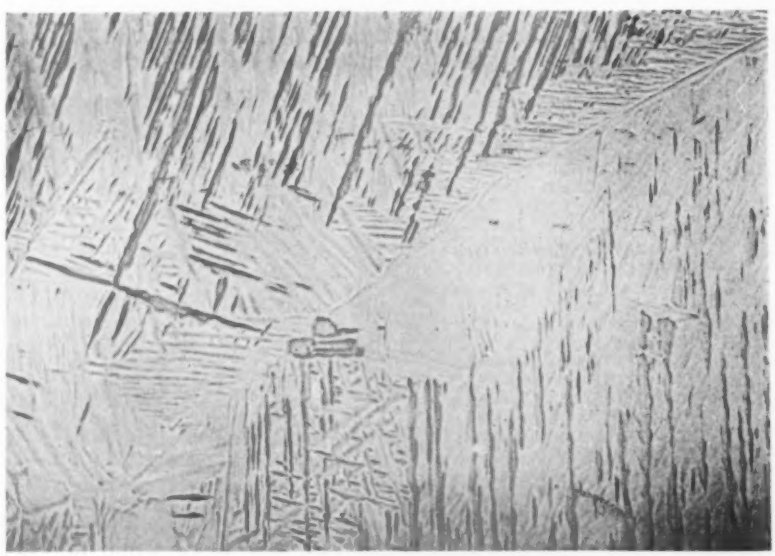

Fig. 6 5% Al alloy

Weld metal. Illustrates a coarse prior beta grain size. The bend ductility and tensile strength are as good as those associated with finer grain sizes. Preheat treatment: 1450° F—60 min → AC. Mechanical properties: 127,000 psi—Ultimate tensile strength; ½ in.—folding distance. × 250.

Pro-eutectoid alpha is precipitated from beta at a relatively rapid rate at all temperatures of supercooling. Generally not more than 20 min are necessary to convert supersaturated beta to the saturated state. At many temperatures the precipitation is complete in less than 5 min. On isothermal transformation by step quenching from the solution treatment to a bath at the transformation temperature, the alpha appears in a Widmanstätten pattern with plate thickness and interplate spacing decreasing with decreasing temperature. The fineness of alpha precipitate produced at any temperature is enhanced by prior water quenching to room temperature. This effect appears to be common to many titanium alloys.

From 0 to 6% Cr, alloys quenched from the beta field transform at least partially to the martensitic product alpha prime. The proportion of alpha prime to beta decreases with increasing alloy content. Concurrently as-quenched hardnesses increase to a peak of about 550 Vhn at the composition at which beta is completely retained. From this trend it is apparent that any hardening influence of alpha prime cannot be distinguished from an anomalous hardening of the beta phase. Parris, *et al.*,[3] have claimed that the hardness of the beta is cooling rate dependent and that at sufficiently rapid cooling the retained beta is relatively soft. As will be reported in later sections, some results were obtained which support this contention. However, there was sufficient inconsistency to make it clear that soft and ductile beta as a quench product is not practicable in commercial heat treatment especially in thicker sheet than that used in this study.

Between 11 and 15% Cr, the beta phase retained to room temperature regains its ductility. The 15% Cr alloy is currently regarded as having interesting strength-ductility combinations. While the beta phase can be retained at cooling rates somewhat slower than water quenching, pro-eutectoid constituents will be rejected quite readily on holding at elevated temperatures.

B. Mechanical Properties of Weldments in a 2% Cr Alloy

The results of heat treatments are summarized in Table 4. In the as-welded state, the 2% Cr alloy has fairly poor bend ductility. From the results of testing after various rates of cooling from the beta field, the properties of the as-welded state approximate those of a water quench. Post treatments of the weld were selected on the basis of prior experience with similar alloys. By step-quench type treatment, the weldment can be rendered ductile within a narrow range of transformation temperatures (1112–1292° F). Tests covering the range 752–1292° F show a progressive deterioration in bend ductility and progressive increase in tensile strength with decreasing transformation temperature.

By introducing a water quench stage between solution treatment and transformation at subcritical temperatures, the bend ductilities are not markedly improved although at 1202° F the results are almost as good as those obtained by direct isothermal transformation.

Eliminating the solution treatment stage in the post treatment gives results at 1202 and 1112° F which are quite as good as those obtained by either of the previous two methods of heat treatment.

Simple air cooling of the 2% Cr alloy yields a ductile condition. By way of examining the correlation between as-welded ductility and prior ductility, a weldment was made from sheet specimens which had previously been air cooled from the solution treatment temperature. The results show that the as-welded state is quite brittle despite the initially ductile state. This would indicate that preheat treatments for the purposes of improving the ductility of the as-welded state are unlikely to be successful. Further experiments with other alloys will support this statement.

It would appear that the welded 2% Cr alloy cannot develop strengths above 110,000 psi without loss of ductility. Furthermore, weldments can be rendered bend ductile by reheating after welding to a temperature between 1100–1200° F for about 30 min. Temperature range more than prior thermal history seems to be the important parameter in heat treatment.

There is no obvious pattern of location of fractures. The heat-affected zone seems most prone to failure in the bend test and the weld metal in the tension test but in neither case is this invariably so.

Four selected hardness plots are shown in Fig. 7. The as-welded state (Curve *C*) shows a pronounced hardness peak in the weld metal zone. It is to be noted that both bend and tensile fractures occurred in the heat-affected zone. Posttreating serves to obliterate variations in hardness across the weld. The hardnesses of post-treated welds show a trend of increasing hardness level with decreasing isothermal transformation temperature, see Curves

Table 4—The Mechanical Properties of Weldments in a 2% Cr Alloy

*Heat treatment**	*Free bend folding distance, in.*	*Bend failure†*	*Ultimate tensile strength, psi*	*Tensile elongation, %*	*Tensile failure†*
A. Unwelded:					
ST→WQ	1 1/16	..	145,800	3	..
ST→AC	0	..	116,500	15	..
ST→FC	1/8	..	99,700	11.7	..
ST→1292° F—20 min→WQ	0	..	113,500	14	..
ST→1112° F—20 min→WQ	1/32	..	113,000	9.7	..
B. Welded and postheat treated:					
As-welded	3 3/4	HA	148,000	0.7	HA
ST→1292° F—20 min→WQ	0	HA	100,000	4.5	WM
ST→1202° F—20 min→WQ	0	BM	92,000	5.8	WM
ST→1112° F—20 min→WQ	0	HA	102,500	3	WM
ST→1022° F—40 min→WQ	1 7/8	BM	117,800	2.5	WM
ST→ 932° F—60 min→WQ	1 3/4	HA	124,000	2.3	HA
ST→ 842° F—60 min→WQ	2 9/16	HA	132,000	3	BM
ST→ 752° F—60 min→WQ	3 1/16	HA	135,500	1.5	WM
ST→WQ→1382° F—30 min→WQ	1 7/16	HA	124,200	2.3	WM
ST→WQ→1202° F—30 min→WQ	3/8	HA	103,000	2	WM
ST→WQ→1112° F—30 min→WQ	1 7/16	HA	119,500	2.5	WM
1382° F—30 min→WQ	1 1/4	HA	121,500	1.3	HA
1202° F—30 min→WQ	0	HA	99,200	11.8	BM
1112° F—30 min→WQ	1/4	HA	110,000	6.5	HA
C. Preheat treated and welded:					
ST→AC	5 1/8	Flaw	119,500	1.5	WM

* ST = solution treatment at 1652° F for 10 min; WQ = water quenched; AC = air cooled.
† BM = base metal; HA = heat-affected zone; WM = weld metal.

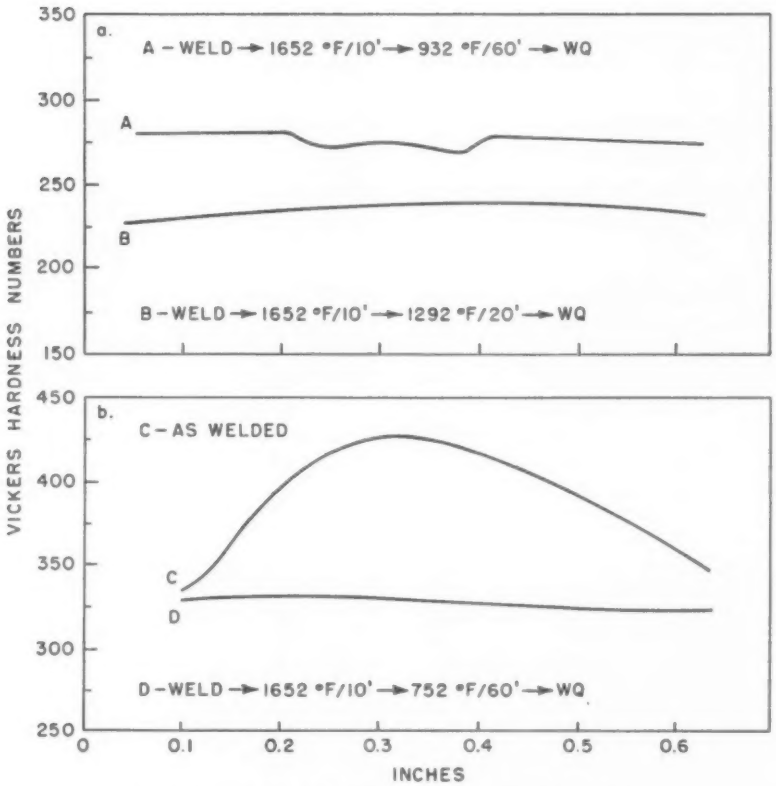

Fig. 7 a and b: Hardness traverses of 2% Cr sheet

B, *A* and *D* in this order (Fig. 7).

It is relatively difficult to recognize characteristic effects in the microstructures of this alloy. The rejection of alpha is so rapid that structures heat treated for more than a few minutes show completed transformations. Moreover, the ratio of alpha to beta and the configurations of alpha are not perceptibly affected in the range of heat treatment temperatures chosen.

C. Mechanical Properties of Weldments in a 5% Cr Alloy

The results of various sequences of heat treatment in both the welded and unwelded state are summarized in Table 5. In the as-welded state the 5% Cr alloy is even more brittle than the 2% Cr alloy. Again this parallels a rate of cooling given by water quenching. Air and furnace cooling from the Beta field create a ductile condition.

As a post treatment of the weld, step-quenching, i.e., isothermal transformation after solution treatment, yields with successive choice of temperatures a progression from complete bend ductility at 1292° F to a quite brittle state at 752° F, with concurrent rise in tensile strength from 96,000 to 145,000 psi.

Quench- and reheat type treatment gives the same trend of results but with higher tensile strengths. Simple reheat type treatment gives somewhat the same pattern. As with the 2% Cr alloy, there is little to choose from the following three sequences of post treatment:

1. Solution treat → 1100° F—20 min → water quench (step-quench type treatment)
2. Solution treat → water quench → 1100° F—20 min → water quench (quench and reheat type treatment)

Table 5—The Mechanical Properties of Weldments in a 5% Cr Alloy

*Heat treatment**	*Free bend folding distance, in.*	*Bend failure†*	*Ultimate tensile strength, psi*	*Tensile elongation, %*	*Tensile failure†*
A. Unwelded:					
ST→WQ	4 7/8	..	178,000	4	..
ST→AC	3/8	..	137,000	12	..
ST→FC	1/4	..	120,000	15	..
ST—1292° F—20 min→WQ	0	..	124,000	13.5	..
ST→1202° F—20 min→WQ	7/32	..	118,000	17.5	..
ST→1112° F—20 min→WQ	3/8	..	136,000	11.5	..
ST→1022° F—20 min→WQ	3/4	..	139,000	6.5	..
B. Welded and postheat treated:					
As-welded	5 5/16	HA	86,200	0.7	WM
ST→1292° F—20 min→WQ	0	HA	96,000	6	HA
ST→1202° F—20 min→WQ	7/32	HA	112,000	11.5	BM
ST→1112° F—20 min→WQ	1/4	HA	127,000	7	BM
ST→1022° F—40 min→WQ	3/4	HA	118,000	5.5	BM
ST→ 932° F—60 min→WQ	4 7/16	WM	150,000	3.5	BM
ST→ 842° F—60 min→WQ	3 1/4	BM	134,200	3	BM
ST→ 752° F—60 min→WQ	4 3/8	BM	145,000	2.5	BM
ST→WQ→1292° F—20 min→WQ	0	HA	116,500	4	HA
ST→WQ→1202° F—20 min→WQ	1/4	HA	116,100	8.5	BM
ST→WQ→1112° F—20 min→WQ	5/8	HA	130,000	5.5	BM
ST→WQ→1022° F—40 min→WQ	1 1/8	WM	132,000	1.5	WM
ST→WQ→ 932° F—60 min→WQ	4 11/16	WM	146,000	1.5	HA
1292° F—20 min→WQ	0	BM	108,000	12.5	BM
1202° F—20 min→WQ	0	BM	109,000	8	BM
1112° F—20 min→WQ	11/16	BM	118,000	4	BM
1022° F—40 min→WQ	1 5/8	BM	133,000	1.5	BM
932° F—60 min→WQ	1 9/16	HA	138,000	2	BM
C. Preheat treatment and welded:					
ST→AC	5 7/16	HA	...	0.5	Flaw

* ST = solution treatment at 1607° F for 10 min; WQ = water quenched, AC = air cooled, FC = furnace cooled.
† BM = base metal; HA = heat-affected zone; WM = weld metal.

Fig. 8 5% Cr Alloy

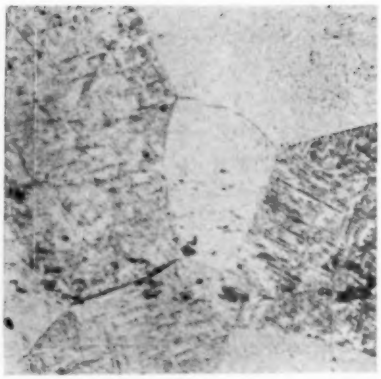

Fig. 9 5% Cr alloy

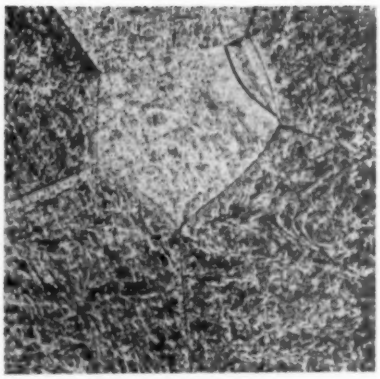

Fig. 10 5% Cr alloy

Figure 8. Weld metal. Postheat treatment: 1607° F—10 min→ 1292° F—20 min→ WQ. Mechanical properties: 96,000 psi—Ultimate tensile strength; zero closure in free bend; 6%—elongation. × 180.
Figure 9. Weld metal. Postheat treatment: 1607° F—10 min→ 1112° F—20 min→ WQ. Mechanical properties: 127,000 psi—Ultimate tensile strength; ¼ in.—folding distance; 7%—elongation. × 180.
Figure 10. Weld metal. Postheat treatment: 1607° F—10 min→ 932° F—60 min→ WQ. Mechanical properties: 150,000 psi—Ultimate tensile strength; 4⅞ in.—folding distance; 3.5%—elongation. × 180.

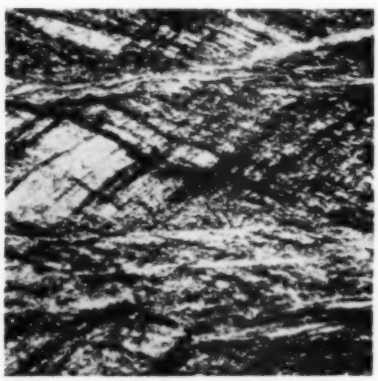

Fig. 11 5% Cr alloy

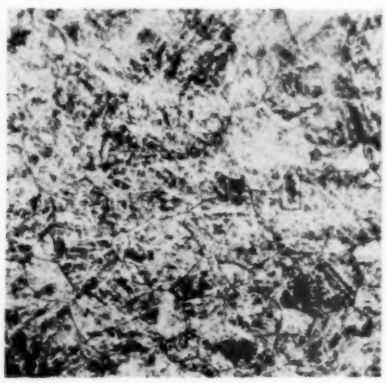

Fig. 12 5% Cr alloy

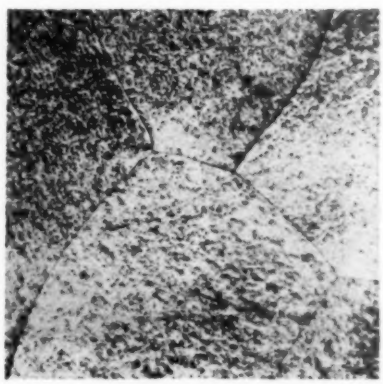

Fig. 13 5% Cr alloy

Figure 11. Base metal. Welding never heated this zone above $\beta/\alpha + \beta$ temperature. Combined weld heating and postheating have caused rejection of fine alpha but retained the cold worked texture. Postheat treatment: 932° F—60 min→ WQ. Mechanical properties: 138,000 psi—Ultimate tensile strength; 1⅞ in.—folding distance; 2%—elongation. × 375.
Figure 12. Heat-affected zone. Fine beta grain size as a result of heating during welding to above $\beta/\alpha + \beta$ temperature. Some evidence of alpha prime in tempered state which derived by cooling from welding. Fine alpha dispersion throughout beta grains. Bend failure occurred here. Postheat treatment: Same as Fig. 11. Mechanical properties: Same as Fig. 11. × 375.
Figure 13. Weld metal. Coarse as-cast beta grain size. Cooled from welding at slow enough rate to suppress formation of alpha prime. Reheating caused rejection of fine alpha dispersion. Postheat treatment: Same as Fig. 11. Mechanical properties: Same as Fig. 11. × 375.

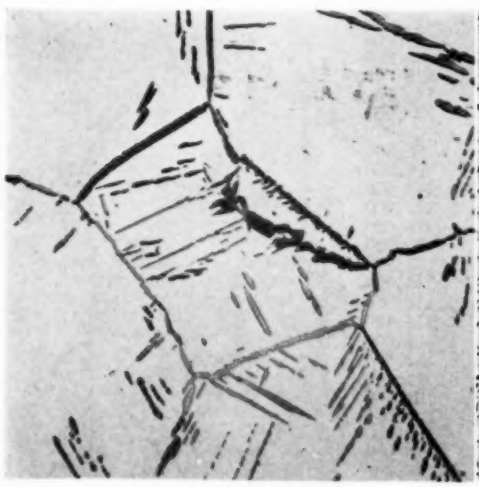

Fig. 14 7% Cr alloy

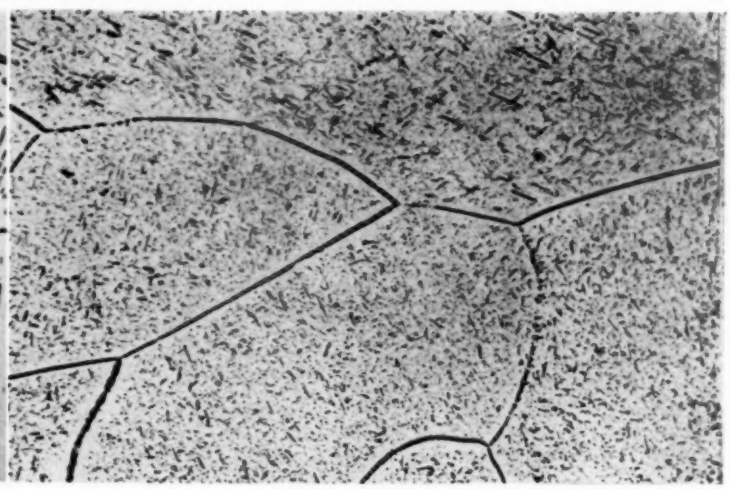

Fig. 15 7% Cr alloy

Figure 14. Weld metal. Postheat treatment: Solution treated→ 1382° F—20 min→ WQ. Mechanical properties: 116,000 psi—Ultimate tensile strength; 5½ in.—folding distance. × 500.
Figure 15. Weld metal. Postheat treatment: Solution treated→ WQ→ 1382° F—20 min→ WQ. Mechanical properties: 160,000 psi—Ultimate tensile strength; 5¼ in.—folding distance. × 500.

3. 1100° F—20 min → water quench (simple reheat type treatment)

The crux of the matter appears to be that for a restoration of ductility to the weldment, an anneal at 1100–1200° F must be included in the post treatment. Controlled cooling rate experiments have not been included in the above statement because a size factor variable is involved which must be studied for each case. Almost complete bend ductility combined with tensile strengths of 120,000–130,000 psi appear to be potentially practicable with the 5% Cr alloy.

Pretreatment to give a ductile condition by air cooling from the beta field did not modify the weld embrittlement.

Figures 8, 9 and 10 illustrate the trend of microstructures with decreasing transformation temperature. The effect seems to be a progressively finer and shorter platelet of alpha. Concurrently the bend ductilities decrease.

The sequence in Figs. 11, 12 and 13 illustrates that the finer beta grain sizes are not necessarily the strong link in the weld. The welding operation provided a wide range of beta grain sizes from the coarse as-cast grains of the weld metal to small beta grains in the heat-affected zone where the maximum temperature exceeded the $\beta/\alpha + \beta$ boundary. On reheating to 932° F for 60 min, a dispersion of alpha appeared throughout the structures of each zone but the outline of the beta grain boundaries was retained. Fracture occurred in the heat-affected zone where the beta grain was relatively fine.

D. Mechanical Properties of Weldments in a 7% Cr Alloy

The results of various heat treatments on welds in a 7% Cr sheet are summarized in Table 6. This composition generally proved brittle in the water-quenched state. However, a number of narrower specimens quenched ostensibly in the same manner exhibited appreciable ductility (free bend folding distance of $^3/_8$ in.). Microexamination of both brittle and ductile specimens showed the same completely retained beta structure. Chemical analyses confirmed identical compositions. It must be inferred that the more ductile specimen received a more vigorous quench because of its smaller size.

The nature of the embrittlement of beta in eutectoid type alloys remains an open question although present thought associates it with preprecipitation effects. However, its frequency of occurrence is sufficient to make it a problem among titanium alloys. The presence of brittle beta in phase mixtures must be expected to have an influence on suitable heat treatments for restoration of weld ductility. In the as-welded state the 7% Cr alloy is unquestionably brittle and usually fails prematurely under tension.

Step-quench treatments developed good ductilities in the narrow range of temperatures between 1112–1292° F. The use of the quench and reheat treatment narrowed the critical temperature range to about 1202° F. In both cases, annealing temperatures above and below the critical zone develop brittle stages. Of the four chromium compositions studied, this alloy is the most difficult to handle.

A number of attempts were made to vary the preheat treatment before welding. In each instance the as-welded state was brittle. It must be concluded as in the case of 2 and 5% Cr alloys that any beneficial effects of pretreatment are erased in the weld metal and in the heat-affected zone.

Step-quenching produces alpha precipitates the shape and quantity of which are dependent on the transformation temperature. The occurrence of ductility, however, seems to correlate more with temperature of transformation than with microstructural configurations. The interpretation is that at the higher temperatures of transformation, the beta retained in the two-phase structures is of the brittle variety. At intermediate transformation temperatures the beta has been enriched beyond the brittle composition range. At low transformation temperatures, the fineness of the alpha dispersion acts to restrict ductility.

An example of the influence of prior quench on the transformation characteristics of beta may be seen by comparing Figs. 14 and 15. While step-quenching precipitates relatively few coarse plates, the fine Widmanstätten pattern of the quenched and reheated weld metal of Fig. 15 fills all the grains. The mode and kinetics of transformation are obviously different from that encountered in the step-quench treatment of Fig. 14. The influence of pretreatment is completely erased by welding, yielding brittle retained beta in the weld metal. This is illustrated in Fig. 16.

E. Mechanical Properties of Weldments of a 15% Cr Alloy

A limited number of experiments were conducted with this alloy. In the as-quenched state, the structure is fully retained beta of a ductile nature. The transformation of the beta phase in spite of the high alloy content is rapid. Table 7 summarizes the results of mechanical

Table 6—The Mechanical Properties of Weldments in a 7% Cr Alloy

*Heat treatment**	*Free bend folding distance, in.*	*Bend failure†*	*Ultimate tensile strength, psi*	*Tensile elongation, %*	*Tensile failure†*
A. Unwelded:					
ST→WQ	$5^5/_{16}$	..	62,000	0	..
B. Welded and postheat treated:					
As-welded	$4^1/_4$	HA	97,500	1	WM
ST→WQ	$5^5/_8$	HA	88,000	1	HA
ST→1382° F—20 min→WQ	$5^5/_{32}$	BM	116,000	0	BM
ST→1292° F—20 min→WQ	$^7/_8$	WM	128,000	2.5	WM
ST→1202° F—20 min→WQ	$^2/_8$	HA	79,500	1.5	Flaw
ST→1112° F—20 min→WQ	$^2/_8$	BM	117,000	0.5	BM
ST→1022° F—40 min→WQ	$3^3/_8$	HA	102,500	0	BM
ST→WQ→1382° F—20 min→WQ	$5^1/_4$	BM	160,000	1.5	WM
ST→WQ→1292° F—20 min→WQ	$3^7/_{16}$	HA	134,000	2	WM
ST→WQ→1202° F—20 min→WQ	$^3/_8$	BM	132,000	4.5	BM
ST→WQ→1112° F—20 min→WQ	$2^1/_4$	HA	111,500	0	BM
ST→WQ→1022° F—40 min→WQ	$4^3/_4$	WM	126,500	0	BM
C. Preheat treated and welded:					
ST→WQ			Extremely brittle		
ST→1202° F—20 min→WQ	$5^1/_{16}$	HA	97,000	0.5	HA
ST→1112° F—20 min→WQ	$5^3/_4$	Flaw	145,500	4	BM; HA
1202° F—20 min→WQ	$5^1/_2$	HA	57,000	0.5	WM
1112° F—20 min→WQ	$5^3/_4$	Flaw	37,000	0.5	Flaw

* ST = solution treatment at 1607° F for 10 min; WQ = water quenched.
† BM = base metal, HA = heat-affected zone, WM = weld metal.

Table 7—The Mechanical Properties of Weldments in a 15% Cr Alloy

*Postheat treatment**	*Free bend folding distance, in.*	*Bend failure†*	*Ultimate tensile strength, psi*	*Tensile elongation, %*	*Tensile fracture†*
As-welded	3/16	HA	85,000	4.5	WM
ST→WQ	3/8	WM	131,500	10	BM
ST→1022° F—20 min→WQ	3/4	HA	135,500	7.5	BM
ST→1112° F—20 min→WQ	3/16	BM	87,000	6.5	BM
ST→1202° F—20 min→WQ	3 11/16	WM	91,000	2	WM

* ST = solution treatment at 1427° F for 15 min; WQ = water quenched.
† BM = base metal, HA = heat-affected zone, WM = weld metal.

testing. Preliminary results indicate that the water-quenched state provides the best combination of strength and ductility. It is also to be noted that the as-welded state is ductile.

F. Discussion on Titanium-Chromium Alloys

The most significant point concerning these alloys is the exceptional brittleness of the medium alloy contents in the as-welded state. While it has been demonstrated that ductilities can be restored by postheat treatment, the danger of cracking in welded assemblies in handling or on heating would seem to militate against their use if any reasonable alternative is available. The same might be said of the RC-130A alloy and, indeed, of all of the eutectoid type alloy systems in which a composition range of brittle beta is encountered. The 15% Cr gives a ductile weld but is hardly superior in strength to what might be obtained in a post-treated 2–4% Cr alloy.

V. THE INFLUENCE OF HEAT TREATMENT ON THE MECHANICAL PROPERTIES OF WELDS IN TITANIUM-MOLYBDENUM ALLOYS

Four alloys containing 3, 6, 10 and 30% Mo, respectively, have been studied in both the welded and unwelded state under various conditions of pre- and post treatment. As with the Ti-Cr alloys, the objectives were to determine the tendencies toward as-welded brittleness as a function of molybdenum content and to investigate the influence of heat treatment in preventing embrittlement or recovering lost ductility. The results serve to classify alloys in this system according to the degree of difficulty to be expected in applied welding.

A. Response of Ti-Mo Alloy to Heat Treatment

The system Ti-Mo is of the simplest type; with increasing molybdenum content, the beta phase is stabilized to lower temperatures successively. There are no known intermediate phases. The origins of heat treatability lie in the basic transformations:

$\beta \rightarrow \alpha + \beta$ (nucleation and growth)
$\beta \rightarrow \alpha'$ (martensitic)

Alpha is precipitated from supersaturated beta at a slower rate than in Ti-Cr alloys: At some elevated temperatures, times of more than 1 hr are needed to reject alpha completely. On isothermal transformation by step-quenching from the solution treatment, the alpha appears in a Widmanstätten pattern with plate thickness and length decreasing with decreasing temperature. In initial stages of transformation above the "knee" of the TTT curves, the alpha is very prone to preferred precipitation at beta grain boundaries. At temperatures below the "knee" of the TTT curves, and upon reheating after a quench from the solution treatment, alpha is rejected uniformly throughout the beta grains in finely dispersed form.

From 0 to 10% Mo, alloys water quenched from the beta field transform at least partially to the martensitic product alpha prime. The proportion of alpha prime to beta decreases with increasing alloy content. The alpha prime appears at best to be only a slight strengthener and does not seem to reduce ductilities. The beta retained by quenching of alloys with 11% Mo or more is soft and ductile. In fact, pure beta in an 11% Mo alloy has a tensile strength which is no greater than that of a 3% Mo alloy annealed to a structure of 90% alpha. Therefore the beta and alpha phases are of about equal tensile strength.

With increasing molybdenum content the rates of transformation: $\beta \rightarrow \alpha + \beta$ are progressively more sluggish. Coincidentally the forgeabilities deteriorate. The 30% Mo alloy represents a threshold composition of maximum thermal stability consistent with a reasonable degree of forgeability.

The dilemma of transformation stability is crucial in the development of weldable alloys. Alloys transforming rapidly or slowly yield welded structures in the same state of equilibrium as the base metal. If the base metal is ductile, the weld should then be as ductile. However, the acceptance of this rule carries with it an inflexibility of choice of strength values. In low titanium alloy contents, the transformation: $\beta \rightarrow \alpha + \beta$ is often insuppressibly rapid and so the structure of the weld is essentially the same as that of the ductile base metal. But, of course, the tensile strengths are low and incapable of elevation by heat treatment.

Fig. 16 7% Cr alloy

Weld and heat-affected zones. Preheat treatment: Solution treated → 1202° F—20 min → WQ. Mechanical properties: 97,000 psi—Ultimate tensile strength; 5¼ in.—folding distance. × 75.

Table 8—The Mechanical Properties of Weldments in a 3% Mo Alloy

*Heat treatment**	*Free bend folding distance, in.*	*Bend failure†*	*Ultimate tensile strength, psi*	*Tensile elongation, %*	*Tensile failure†*
A. Heat treated and unwelded:					
ST→WQ	3	..	183,500	6.5	..
1472° F—60 min→WQ	1/8	..	117,500	10	..
B. Welded and postheat treated:					
As-welded	7/8	HA	141,000	2.5	HA
ST→WQ	3/8	WM	136,000	4.5	WM
ST→1472° F— 5 min→WQ	1/16	WM	112,000	7	WM
ST→1472° F—60 min→WQ	1/4	WM	111,000	6.5	WM
ST→1292° F— 5 min→WQ	1/16	BM	107,000	9.5	BM
ST→1292° F—60 min→WQ	1/16	WM	107,000	9.5	WM
ST→1112° F— 5 min→WQ	13/16	BM	107,500	2.5	WM
ST→1112° F—60 min→WQ	3/8	BM	110,000	1.5	WM
ST→WQ→1472° F—60 min→WQ	1/8	WM	114,500	6	WM
ST→WQ→1292° F—60 min→WQ	1/8	HA	122,000	6.5	WM
ST→WQ→1112° F—60 min→WQ	15/16	HA	126,000	0	WM
1472° F—60 min→WQ	1/8	HA	109,000	19.5	BM
1292° F—60 min→WQ	0	BM	106,000	11.5	BM
1112° F—60 min→WQ	3/8	WM	101,500	10	BM
C. Preheat treated and welded:					
ST→WQ	9/16	BM	94,500	4.5	BM
1472° F—60 min→WQ	3/8	WM	101,000	10.5	BM

* ST = solution treated at 1788° F for 15 min in helium; WQ = water quenched.
† BM = base metal; HA = heat-affected zone; WM = weld metal.

In the development of high-strength, high - ductility, transformation - stable alloys, one is driven to the very high alloy contents where solid solution hardening is effective. Whether any particular alloying element can satisfy these requirements cannot be foretold.

B. Mechanical Properties of Weldments in a 3% Mo Alloy

Three basic types of post treatments were studied in terms of their influence on the mechanical properties of weldments. In addition, two conditions of pretreatment were analyzed. The results of bend and tensile testing are summarized in Table 8. The as-welded state is ductile and unusually strong in tension. Heat treatments therefore only serve to provide some minor improvement in bend ductility and perhaps an increase in tensile strength. Figure 17 shows the serrated alpha prime structure, the product of solution treatment and water quenching; it is strong and ductile. As it turns out, the bend ductility can be improved to permit almost complete closure in bending by any post treatment conducted at or above 1292° F. No post treatment however succeeded in raising the tensile strength above the as-welded condition. In retrospect, there seems to be little advantage derived in employing post treatments.

The unusually high tensile strength in the unwelded state after solution treating and water quench is suspected of contamination, as it appears to be quite out of line with the rest of the data.

C. Mechanical Properties of Weldments in a 6% Mo Alloy

The results of pre- and post treatments on the mechanical properties of welds are summarized in Table 9. The as-welded state is bend ductile but low in strength. The postheat treatments were therefore directed to increasing the strength. The step-quench experiments show that ductility can be exchanged for strength. At 1202° F, transformation develops much improved strengths while still maintaining good ductilities. Transformation temperatures below 1202° F embrittle the weldment.

Table 9—The Mechanical Properties of Weldments in a 6% Mo Alloy

*Heat treatment**	*Free bend folding distance, in.*	*Bend failure†*	*Ultimate tensile strength, psi*	*Tensile elongation, %*	*Tensile failure†*
A. Heat treated and welded:					
ST→WQ	1/16	..	143,000	16.5	..
1382° F—60 min→WQ	0	..	139,000	2.5	..
B. Welded and postheat treated:					
As-welded	3/16	WM	87,500	4	WM
ST→WQ	3/16	WM	83,500	13.5	HA
ST→1382° F— 5 min→WQ	1/16	HA	85,000	17.5	BM
ST→1382° F—60 min→WQ	1/8	BM	112,000	17.5	BM
ST→1202° F— 5 min→WQ	3/4	HA	164,500	5	BM
ST→1202° F—60 min→WQ	1 1/4	HA	157,000	4.5	BM
ST→1022° F— 5 min→WQ	4	BM	186,000	1	BM
ST→1022° F—60 min→WQ	3 1/16	BM	200,500	0	BM
ST→WQ→1382° F—60 min→WQ	2 1/8	WM	87,000	9.5	WM
ST→WQ→1202° F—60 min→WQ	1	WM	103,000	4	WM
ST→WQ→1022° F—60 min→WQ	4 11/16	WM	129,000	1	WM
1382° F—60 min→WQ	0	BM	128,000	7	BM
1202° F—60 min→WQ	0	BM	135,000	6	BM
1022° F—60 min→WQ	2 3/8	WM	117,500	2.5	HA
C. Preheat treated and welded:					
ST→WQ	1/4	WM	128,000	9	BM
1382° F—60 min→WQ	0	BM	132,000	6	BM

* ST = solution treated at 1742° F for 15 min; WQ = water quenched.
† BM = base metal; HA = heat-affected zone; WM = weld metal.

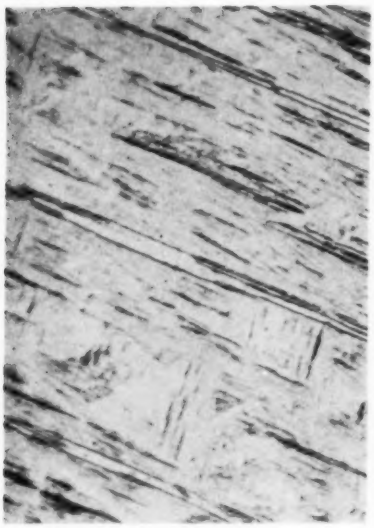

Fig. 17 3% Mo alloy

Weld metal. Post heat treatment: Solution treated → WQ. Mechanical properties: 136,000 psi—Ultimate tensile strength; ⅜ in.—folding distance. × 500.

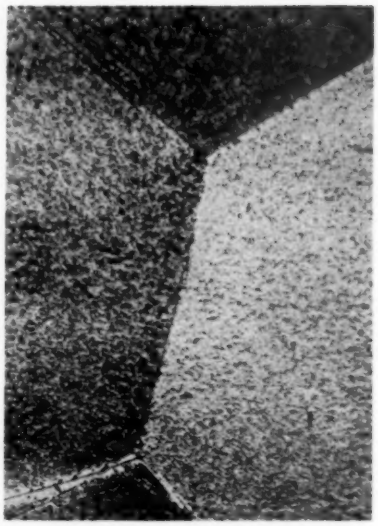

Fig. 18 10% Mo alloy

Heat-affected zone. Heat treatment: None. Mechanical properties: 122,000 psi—Ultimate tensile strength; 4 11/16 in.—folding distance. × 500.

The quench and reheat treatment seems to be inferior both in terms of ductility and strength. The simple reheat treatment preserves ductility above 1202° F but does not increase the strength at 1202° F so markedly.

Preheat treatment apparently improves the strength of the as-welded state.

D. Mechanical Properties of Weldments in a 10% Mo Alloy

The results of pre- and post treatments on the mechanical properties of weldments are summarized in Table 10. The as-welded structure shown in Fig. 18 has a fine alpha dispersion which is usually brittle. The structure indicates that in this portion of the weld, the cooling rate was of the order of magnitude of an air cool. Re-solution treating and quenching restores the ductility but the strength is low. Since only a small amount of alpha prime is formed on quenching, this behavior is indicative of the small strength contribution of beta to the structure. Step-quench treatment of the welds recovers ductility at annealing temperatures between 1382–1202° F. At 1022° F the transformation structure is bend brittle. On the other hand, between 1202 and 1022° F, tensile strengths rise sharply; optimum combinations of ductility and strength should resort from isothermal treatments within this temperature range. On quenching and reheating, bend ductilities and strengths are more dependent on annealing temperature. Simple reheating of the as-welding sheet offers the best promise of high strength-ductility combinations. Therefore from a practical point of view little is to be gained by including a solution treatment stage.

E. Mechanical Properties of Weldments in a 30% Mo Alloy

Only a limited quantity of a 30% Mo alloy in sheet form was produced successfully. Difficulty was encountered in forging and several cases of severe contamination occurred. The results of experiments designed to test the transformation tendencies of this alloy are summarized in Table 11. While the as-welded state is ductile and strong, there is no question that postheating can induce transformations.

The microstructures confirm that transformation products do occur on heat treatment. Figure 19 shows the structure of an alloy air cooled from the beta field. Air cooling and furnace cooling cause severe bend embrittlement.

F. Discussion on Titanium-Molybdenum Alloys

By comparison with titanium-chromium alloys, the single most important feature is the ability of medium alloy contents* to produce ductile welds without postheat treatment. In the case of 6% Mo, post treatment increases the strength at some sacrifice in ductility. Most of the alloys are capable of considerable strengthening

* Experience from other work suggests that this composition range includes 2–8% Mo.

Table 10—The Mechanical Properties of Weldments in a 10% Mo Alloy

*Heat treatment**	*Free bend folding distance, in.*	*Bend failure†*	*Ultimate tensile strength, psi*	*Tensile elongation, %*	*Tensile failure†*
A. Heat treated and unwelded:					
ST→WQ	0	..	105,500	29.5	..
1382° F—60 min→WQ	0	..	109,000	22.5	..
B. Welded and postheat treated:					
As-welded	4 11/16	WM	122,000	0.8	BM
ST→WQ	0	BM	101,000	13.5	BM
ST→1382° F— 5 min→WQ	1/8	BM	111,500	7	BM
ST→1382° F—60 min→WQ	7/16	BM	98,000	2	BM
ST→1202° F— 5 min→WQ	7/16	WM	105,800	9	BM
ST→1202° F—60 min→WQ	1/8	BM	108,500	3	BM
ST→1022° F— 5 min→WQ	3 13/16	HA	175,000	1.5	BM
ST→1022° F—60 min→WQ	3 3/4	WM	159,000	1	HA
ST→WQ→1382° F—60 min→WQ	7/8	BM	110,000	3	BM
ST→WQ→1202° F—60 min→WQ	1 1/16	HA	130,000	3.5	BM
ST→WQ→1022° F—60 min→WQ	2 3/4	HA	171,000	1.5	WM
1382° F—60 min→WQ	0	BM	107,000	13.5	BM
1202° F—60 min→WQ	0	BM	116,200	3.5	BM
1022° F—60 min→WQ	1/4	BM	150,500	2	HA
C. Preheat treated and welded:					
ST→WQ	4 1/16	HA	106,200	5.5	HA
1382° F—60 min→WQ	1/32	BM	100,500	16.5	BM

* ST = solution treated at 1652° F for 15 min in helium; WQ = water quenched.
† BM = base metal; HA = heat-affected zone; WM = weld metal.

Table 11—The Mechanical Properties of Weldments in a 30% Mo Alloy

*Heat treatment**	*Free bend folding distance, in.*	*Bend failure†*	*Ultimate tensile strength, psi*	*Tensile elongation, %*	*Tensile failure†*
A. Heat treated and unwelded:					
ST→WQ	1/16	..	88,800	2.5	..
ST→AC	0	..	142,500	2	..
ST→FC	1/8	..	156,500	4	..
B. Welded and postheat treated:					
As-welded	0	..	142,000	3	..
ST→WQ	2 5/8	HA	128,800	1	BM
ST→AC	4 3/8	HA	99,600	0.5	HA
ST→FC	4 3/4	HA	103,900	3.5	HA
ST→1022° F—5 hr→WQ	1/8	HA	126,300	1	HA

* ST = solution treated at 1202° F for 30 min in helium; WQ = water quenched; AC = air cooled; FC = furnace cooled.
† BM = base metal; HA = heat-affected zone; WM = weld metal.

Fig. 19 30% Mo alloy

Weld metal. Postheat treatment: Solution treated→ AC. Mechanical properties: 99,600 psi—Ultimate tensile strength; 4⅜ in.—folding distance. × 1000.

Table 12—Summary of Optimum Bend Ductility-Tensile Strength Combinations Developed in Various Binary Titanium Alloy Welds

Ultimate tensile strength, psi	*Free bend folding distance, in.*	*Alloy, %*	*Postheat treatment**
120,000–130,000	1/8	3 Al	As-welded
	0	5 Al	1550° F—30 min
	1/4	5 Cr	ST→1112° F—20 min
	1/8	3 Mo	ST→WQ→1292° F—60 min
	0	6 Mo	1382° F—60 min
	1/8	30 Mo	ST→1022° F—5 hr→WQ
130,000–140,000	3/8	RC-130A (4.6 Mn)	ST→1335° F—30 min
	1/4	5 Al	As-welded
	5/8	5 Cr	ST→WQ→1112° F—20 min
	3/8	7 Cr	ST→WQ→1202° F—20 min
	3/8	15 Cr	ST→WQ
	3/8	3 Mo	ST→WQ
	0	6 Mo	1202° F—60 min
140,000–150,000	1/4	RC-130A (6.8 Mn)	ST→1335° F—60 min
	1/2	RC-130A (4.6 Mn)	1335° F—60 min
	7/8	3 Mo	As-welded
	0	30 Mo	As-welded
150,000–160,000	3/8	RC-130A (8.8 Mn)	1335° F—30 min
	1 1/4	6 Mo	ST→1202° F—60 min
	1/4	10 Mo	1022° F—60 min
160,000–170,000	3/4	6 Mo	ST→1202° F—5 min
170,000–180,000	2 3/4	10 Mo	ST→WQ→1022° F—60 min
180,000–190,000	4	6 Mo	ST→1022° F—5 min
190,000–200,000	3 1/16	6 Mo	ST→1022° F—60 min

* ST = solution treated; WQ = water quenched.

by heat treatment. From an alloy development viewpoint, the beta stabilizing type alloy (including Ti-Mo, -V, -Ta and certain ternary systems) is more suitable for the development of weldable alloys than the eutectoid systems (including Ti-Cr, -Fe, -Mn).

VI. SUMMARY AND DISCUSSION

A variety of alloys and compositions has been studied with a view to establishing an understanding of the basic problems of ductile weldments at various strength levels. The complexity in choice of alloy and composition has been compounded with selection of heat-treatment cycles. The program has accordingly been so broad that time has not permitted the multiple checking of each mechanical property reported. The readers are urged to examine the data with a view to recognizing trends rather than singular instances of exceptional behavior. However, in the interests of alloy development, a selection of superior ductilities developed at various strength levels has been collected in Table 12.

The three alloy systems chosen for study proved to have individual characteristics. They might be briefly recapitulated as follows:

1. *Ti-Al alloys.* The $\beta \rightarrow \alpha$ transformation is insuppressible. Therefore at room temperatures only all-alpha structures are encountered irrespective of prior thermal history.

2. *Ti-Cr alloys.* The $\beta \rightarrow \alpha + \beta$ transformation is suppressible and can be induced in controlled fashion. A wide range of compositions occurs in which the retained beta structures are exceedingly brittle. The occurrence of this anomalously brittle beta makes the conditions stringent for developing satisfactory ductility.

3. *Ti-Mo alloys.* The $\beta \rightarrow \alpha + \beta$ transformation also is suppressible and can be induced in controlled fashion. Choice of transformation temperature can develop a range of favorable properties, the range being broader at higher alloy contents. The quench product alpha prime does not induce excessive brittleness nor is it an exceptional strengthener.

A number of alloys proved ductile in the as-welded state. A somewhat larger number was brittle. In almost every case, post treating either improves ductility or increases strength or both. No alloys were encountered which could not be rendered bend ductile if they had been ductile previous to welding. No claim is made that the optimum mechanical properties were developed for each alloy. The aim in selection of posttreatment cycles was to illustrate basic procedures and trends which can be obtained by systematic testing. Of the three posttreatment cycles:

1. Solution treat→isothermal transformation→water quench
2. Solution treat→water quench→isothermal anneal→water quench
3. Isothermal anneal→water quench

each approaches equilibrium by a different path. No single approach is invariably superior to the others. This leads of necessity to the statement that no single posttreatment cycle can be universally applied to all titanium alloys: Basically each alloy is an individual and in its assessment one must be prepared to conduct a systematic appraisal of the relative merits of each of the three cycles. It is hoped that the systems of investigations used in this work will guide the reader in his approach to new alloys.

The weight of evidence (except for one isolated instance) is against the feasibility of preheat treatments influencing the mechanical properties of the as-welded state. As long as the embrittlement derives from transformations in the weld and heat-affected zones, pre-treatment can have but little influence since by re-solution treatment and/or fusion followed by solidification inherent to the welding operation, all prior thermal history is erased. The role of pre-heat treatment must be relegated to the development of mechanical properties particularly required by the forming and assembly operation preceding the welding itself.

The single most important parameter in heat treatment is temperature. Among those alloys for which the rejection of alpha is suppressible, tensile strengths generally increase with decreasing heat treatment temperature. There is generally a concurrent decrease in ductility with decreasing heat treatment temperature except when the retained beta is anomalously brittle. In these instances both a high-temperature and a low-temperature brittle zone occurs. One can recognize from the microstructure at what approximate degree of supercooling a given specimen has been heat treated. A series of microstructures has been integrated in the paper with the objective of illustrating salient correlations between heat treatment, mechanical properties and microstructure. The size and geometry of alpha precipitates are clearly shown to be dependent on thermal treatment. In step-quench type treatment, the alpha appears as plate, the thickness and length of which decrease with decreasing transformation temperature. At some low supercooling temperature, the alpha precipitate becomes extremely fine and uniformly dispersed. This latter type of structure was repeatedly shown to be indicative of brittle behavior. On quenching and reheating, the Widmanstätten patterns of rejections are almost entirely replaced by fine uniform precipitation with particle fineness dependent on temperature.

There was repeated evidence that coarse grain sizes in the weld metal and heat-affected zones are not deleterious to mechanical properties.

It has been pointed out in the text that thermally stable welding alloys, that is, alloys whose mechanical properties are unchanged by the welding operation, fall into two categories:

1. Alloys which are all or nearly all alpha irrespective of heat-treatment or welding cycle.
2. Alloys for which the beta phase is exceedingly sluggish to reject alpha under conditions of metastability.

In the former category are the Ti-Al alloys and low binary compositions (<2%) of the beta stabilizing elements. Only the Ti-Al alloys are potentially capable of providing a wide range of strength levels through solid solution hardening. No beta-stable alloy has yet been discovered. The 15% Cr and 30% Mo compositions represent approximate limits of forgeability and yet both alloys have been shown to be capable of transformation under thermal treatment conditions likely to be encountered in welding.

Hardness plots in other materials have generally found usefulness as a convenient method of locating potential sources of brittleness in a weld. The ability to interpret in such fashion has been based upon known correlations between hardness and ductility. Experience gained with hardness plots on titanium alloys, however, indicates that hardness as a criterion of ductility is not reliable. Many instances have been noted where bend and tensile failures occurred at positions other than points of maximum hardness. In general, however, it seems true that if a level of hardness of 400 Vhn or more is reached in a weld, the weldment will exhibit poor ductility in bending. It is useful to note at this point that no general correlation appears to exist between ductility in bending and ductility (per cent elongation) in tension.

ACKNOWLEDGMENTS

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Acknowledgment is also due to C. A. Johnson for his metallographic work and to Dr. J. M. Parks who was in charge of this study in its early stages.

Reference

[1] DeLazaro, D. J., and Rostoker, W., "Correlation Between Heat Treatment, Microstructure and Mechanical Properties of Ti-Mo Alloys," *Trans. ASM*, preprint No. 8, 1953.

[2] DeLazaro, D. J., and Rostoker, W., "Influence of Oxygen Contents on Transformation Characteristics in a Ti Alloy Containing 11% Mo," *Acta Metallurgica*, vol 1, p 674 (November 1953).

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WRC Bulletin No. 17

The Welding Research Council has just issued Bulletin No. 17 of its Bulletin Series. This Bulletin is entitled, "A Critical Survey of Brittle Failure in Carbon Plate Steel Structures Other Than Ships," by Professor M. E. Shank, Department of Mechanical Engineering, Massachusetts Institute of Technology. This report was prepared for the Committee on Ship Structural Design, of the National Academy of Sciences—National Research Council. The Committee on Ship Structural Design is advisory to the Ship Structures Committee which supported the project as part of its research program.

No similar correlation on nonship failure data exists, and this survey was therefore undertaken in order to supplement the study of ship failures.

Copies of this 48 page Bulletin may be ordered from the American Welding Society, 33 West 39th Street, New York 18, New York. Price $2.00.

Evaluation of Notch-Bend Specimens

The Charpy V energy transition curve provides the most significant and practical method of correlation to service performance of welded structures based on the use of small notch-bend specimens

by P. P. Puzak and W. S. Pellini

Abstract

The energy, fracture appearance and ductility (lateral contraction) transition characteristics of Charpy V, Charpy Keyhole and Schnadt Coheracic specimens were evaluated with respect to relative significance and practicability for correlation to service performance of welded structures. It is concluded that the Charpy V energy transition curve provides the most significant and practical method of correlation based on the use of small notch-bend specimens.

The limitations of the use of Charpy V transition data for different classes of structural steels (rimmed and semikilled vs. fully killed) are discussed. A criterion of energy which is determined to be proper for a given type of steel may not necessarily apply to a different type. It is demonstrated that Charpy V specimens *per se* show differences in fracture behavior which depend on the type of steel.

INTRODUCTION

SMALL notch-bend specimens of various sizes and designs have been employed for many years to evaluate qualitatively the relative resistance of steels to brittle fracture. More recently, attempts have been made to correlate such tests with service performance. The most reliable correlation established to date resulted from the investigation by the National Bureau of Standards[1] of the Charpy V transition characteristics of rimmed and semikilled structural steels taken from ship fractures. This investigation demonstrated that the initiation and propagation of brittle fracture occurred when the service temperature corresponded to temperatures related to the lower portion of the Charpy V transition curves of the fracture steels. Crack initiation and propagation tests conducted at the Naval Research Laboratory[2] on full thickness plates of similar steels showed the same kind of correlation with the Charpy V curve as that developed by the National Bureau of Standards, i.e., ready initiation and propagation of brittle fractures could be obtained only at temperatures related to lower regions of the Charpy V transition curve. However, when fully killed, high-tensile and low alloy steels were investigated, ready initiation and propagation of brittle fractures were obtained at temperatures related to higher positions on the Charpy V transition curves.

It now appears possible, at least for the rimmed and semikilled structural steels, to evaluate the significance of the transition characteristics of Keyhole specimens which are widely used in this country and of Schnadt specimens[3] which are claimed to be superior by European proponents, by calibration against the Charpy V energy transition curve. Eventually a decision should be made as to the most desirable specimen and transition feature for use in service correlation, i.e., both with respect to significance and practicality.

If the Charpy V energy curve is used for the calibration involving other types of steels, it is essential that its variable correlation with crack initiation and propagation characteristics of various classes of steels should be investigated further since the Naval Research Laboratory work shows a danger in the extension to other classes of steels of the initial correlation obtained by the National Bureau of Standards for the rimmed and semikilled ship plate. In this respect it is of interest to determine if the fracture process of Charpy specimens differs for different types of steels, i.e., if the Charpy test *per se* shows differences which may be related to the type of steel.

The available knowledge relative to the interrelationships of small specimens is exceedingly limited even for the semikilled and rimmed structural steels which have been investigated most extensively. The question of differences in fracture initiation and propagation characteristics of small specimens with type of steel represents an essentially virgin field. The purpose of this paper is to present an analysis of data obtained as part of various investigations conducted at this Laboratory which clarifies the relative usefulness and limitations of various types of specimens for correlation with service performance.

COMPARISONS OF SPECIMENS

The problem of correlation has been complicated by the various criteria involving energy, fracture appear-

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ance and prefracture deformation (ductility) which have been selected to define the ductile-brittle transition that occurs in steels. The fallacy of attempting correlation between specimens by an indiscriminate mixing of criteria for determining transition temperatures is now generally recognized. The errors involved became apparent with the realization of the existence of two kinds of transitions: a *fracture transition* involving a change from shear to cleavage type fracture but still associated with appreciable prefracture deformation, and a *ductility transition* involving a sharp change from high to nil-levels of prefracture deformations. For the latter transition the authors prefer the designation *nil-ductility transition*. The concepts of these two kinds of transitions have been discussed previously.[4]

The energy transition curve of Charpy Keyhole specimens shows a relatively sharp drop (scatterband range) which has been demonstrated by Vanderbeck and Gensamer[5] to represent a ductility transition. The Charpy V energy transition curve ordinarily shows no evidence of a sharp ductility transition; however, by nonconventional loading, Harris, Rinebolt and Raring[6] have demonstrated its existence.

In previous work the authors reported on the relationships of the energy transition curves for Charpy V, Charpy Keyhole and Schnadt (coheracic) specimens for semikilled and rimmed steels. Figure 1 shows the design features of these specimens. For purposes of this report fracture and ductility transition curves were obtained and related to the previously established energy transition curves. Typical relationships between the three specimens with respect to three types of transition criteria are illustrated in Fig. 2. The curves shown were established as reliably as possible by the utilization of a greater number of specimens than normally (20) employed. It is observed that relatively smooth curves are obtained for energy, fracture appearance and lateral contraction at the base of the notch for the Charpy V and Schnadt specimens. The keyhole fracture and lateral contraction curves reveal scatterband regions concomitant to that ordinarily observed for the keyhole energy transition.

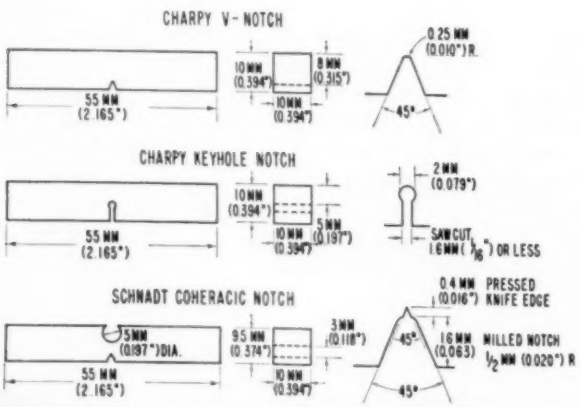

Fig. 1 Design features of Charpy and Schnadt notch-bend specimens

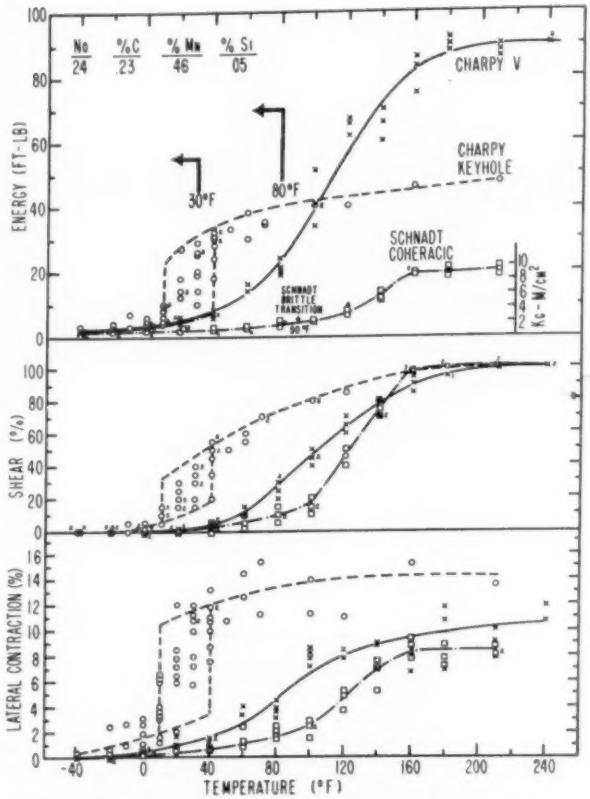

Fig. 2 Typical relationships of energy, fracture and ductility transitions for ship plate steel

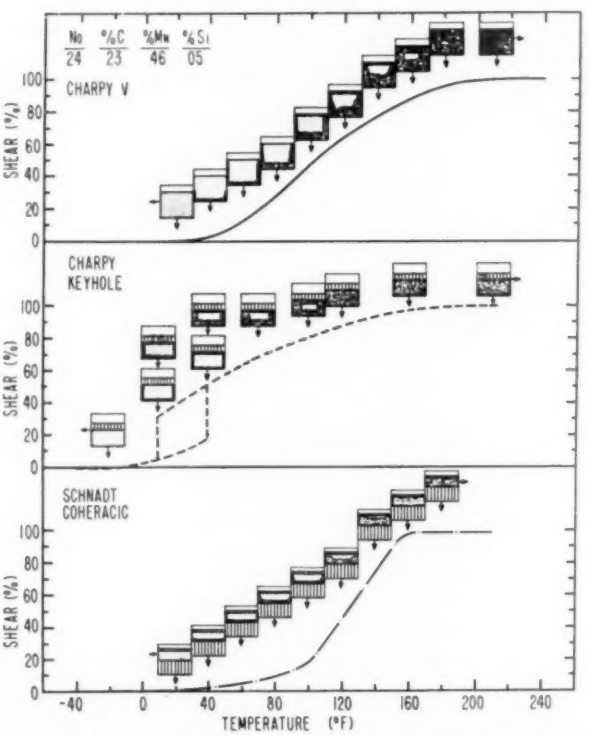

Fig. 3 Characteristic differences in the transition of fracture appearance of Charpy and Schnadt specimens

Figure 3 illustrates characteristic differences in the process of fracture of the three specimens which cannot be represented by a simple plotting of percent shear in the fracture transition curves. The initial appearances of the first evidences of cleavage (brittle) fracture are located centrally in the V and keyhole specimens; however, the Schnadt specimen develops such initial cleavage fracture immediately below the notch. The presence of a shear condition at the base of the notch, therefore, is lost immediately upon entering the transition range by the Schnadt specimen, but persists until some intermediate or low position for the V and Keyhole specimens. Each of the three specimens develops a shear layer along the free, side surfaces (shear lip). For the Charpy V tests, the base of notch shear and side shear are observed to disappear upon decreasing temperature of test in two separate stages with the base of notch shear being eliminated first and then followed in turn by the elimination of the side shear. The keyhole specimens lose both the base of notch shear and the side shear simultaneously in the scatterband region. The Schnadt specimen loses its side shear and notch shear in the same sequence as the Charpy V specimen except that the interval between the two cycles is much greater. From Figs. 2 and 3, it becomes apparent that the transition behavior and fracture mechanism varies considerably for the different specimens. These inherent differences suggest that any correlation which is developed between specimens must necessarily be of an empirical nature.

EVALUATION OF VARIOUS SPECIMENS FOR SERVICE CORRELATION USE

The principal features of the correlation of Charpy V energy transition curves for rimmed and semikilled steels to ship performance and to the Naval Research Laboratory crack starter tests are demonstrated in Fig. 4. The two arrows depict the ranges which are significant to the initiation and propagation of brittle fractures, as will be explained by reference to Fig. 2.

The arrows shown in Fig. 2 refer to results of the Naval Research Laboratory crack starter tests for the steel. At temperatures below 30° F crack initiation occurred without prior plastic deformation, i.e., the Crack-Starter Explosion Bulge Test showed a "flat break" and the Drop Weight Test fractured under conditions of nil deformation loading. At temperatures below 80° F the explosion test plate fractured completely while at higher temperatures only short fractures were obtained. It may be noted that this behavior is the same as predicted by the National Bureau of Standards correlation, i.e., initiation of fractures without prior plastic deformation (ship loading condition) at temperatures below Charpy V 10 ft-lb (usually 5–8 ft-lb) and easy propagation only to temperatures below 20 ft-lb.

Calibration of the various other transition curves of Fig. 2 with the significant Charpy V energy transition criteria of approximately 10 and 20 ft-lb (arrow positions) indicates the following possibilities for direct correlation, i.e., excepting correlations based on temperature shifts (Δt):

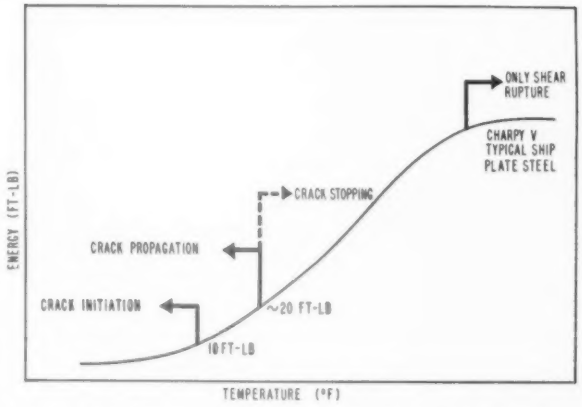

Fig. 4 Correlation to Charpy V energy transition for ship plate steels

1. Upper limit of the Keyhole scatterband (energy, fracture or ductility) correlates with crack initiation.
2. Schnadt curves cannot be correlated with crack initiation since the respective transitions are essentially completed at higher temperatures.
3. Charpy V fracture and energy transition curves may be correlated with crack initiation at approximately 0% shear and 1% lateral contraction respectively.
4. Charpy V fracture and energy transitions may be correlated with crack propagation at approximately 30% shear and 5% lateral contraction respectively.
5. Only the fracture transition of the Keyhole specimen may be correlated with crack propagation (approximately 70% shear). The energy or ductility transition curves cannot be used because of the nearly flat shelf which is developed at the critical temperature range.
6. Schnadt energy, fracture and ductility transitions may be correlated with crack propagation at approximately 2 kg-m/cm², 10% shear and 2% lateral contraction respectively. It is of interest that the 2 kg-m/cm² criterion is considered significant in this respect by Schnadt based on his experience with service performance.

While it is of interest to recognize the various possibilities of correlation it must be recognized that only the energy curves provide for a practical approach to the problem. The determination of fracture transition curves involves estimation variables and the determination of ductility transition curves is excessively time consuming. The Charpy V energy transition curve is the only one which permits the simultaneous evaluation of crack initiation and crack propagation; therefore, it must be concluded that the Charpy V test represents the most significant and practical correlation method.

As discussed previously, the Naval Research Laboratory crack-starter tests of both rimmed and semikilled ship plate steels correlated to Charpy V energy transi-

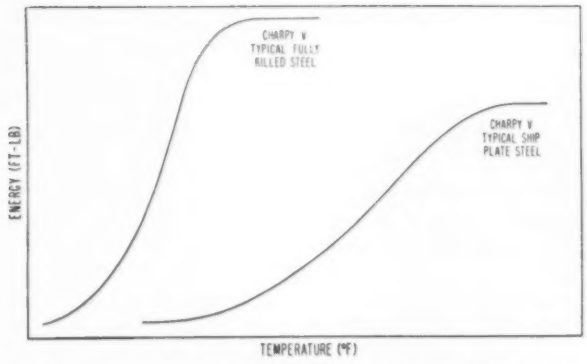

Fig. 5 Comparison of Charpy V energy transition curves

tions in the same manner as ship steel fractures in service; however, entirely different relationships were observed in crack-starter tests of fully killed mild steels and fully killed high-tensile steels for which no service performance data are available. For fully killed mild steels, fracture initiation in the drop weight tests was obtained at temperatures equivalent to Charpy V 15 to 25 ft-lb and for the fully killed high-tensile steels to Charpy V values as high as 40 ft-lb. Similarly, complete fractures in the bulge tests were obtained at temperatures corresponding to the upper portions of the Charpy V energy curves, i.e., at energy values which depending on the level of the upper shelf, could be so high as 80–90 ft-lb. Unfortunately, there are no service performance data for fully killed steels which may be used to test the implications of the crack starter tests. As another approach to this problem it was decided to analyze critically for possible differences in the mechanism of fracture of Charpy V specimens for rimmed and semikilled steels as compared to fully killed steels.

FEATURES OF CHARPY V TRANSITION CURVES FOR VARIOUS STEELS

An examination of the shape of the Charpy V transition curves indicates marked differences between the various classes of steels. Figure 5 depicts Charpy V energy transitions typical of rimmed and semikilled steels as compared to the fully killed steels. In addition to a shift in the transition range to lower temperatures the curves of fully killed steels generally display steeper slopes and higher maximum energy levels.

It was observed previously in the process of conducting Charpy V tests of the various steels that the shear lip on the lateral surfaces of fractured Charpy specimens appeared to vanish at different levels of energy for the rimmed and semikilled steels as compared to fully killed steels. Since the shear lip relates to conditions of fracture propagation, and therefore represents an important feature of the fracture process, one method of evaluating differences in the steels was indicated. Lateral contraction measurements at the notch position provided a method of evaluating conditions related to the initiation of fracture. Accordingly, a number of steels for which complete data were available were selected for investigation with respect to these two methods of evaluation. Table 1 lists the chemical analy-

Table 1

Type	Code*	Thickness, Inches	C %	Mn %	Si %	Al %	P %	S %	Ni %	Cr %	Mo %	Cu %	Ti %	V %
ETS	3N	1	0.15	0.95	0.22	—	0.017	0.023	0.11	0.15	0.013	0.19	0.01	0.02
	4N	1	0.16	1.33	0.26	0.014	0.021	0.028	0.05	0.26	—	0.01	0.05	0.01
	36n	1	0.15	1.02	0.30	0.005	0.024	0.027	0.07	0.20	0.030	0.10	0.05	0.12
	37n	1	0.14	1.10	0.28	0.005	0.011	0.038	0.05	0.06	0.030	0.10	0.05	0.10
	38n	1	0.13	1.23	0.31	0.005	0.021	0.031	0.05	0.14	0.030	0.10	0.02	0.13
	39n	1	0.13	1.05	0.23	0.005	0.017	0.037	0.03	0.06	0.030	0.10	0.00	0.10
Fully killed	9(N,A)	3/4	0.12	0.74	0.17	—	0.029	0.036	0.21	0.13	0.032	0.04		
	10m	3/4	0.18	0.54	0.25	—	0.015	0.029	0.18	0.11	0.050	0.20		
	15	1	0.22	0.52	0.21	—	0.019	0.034	0.03	0.11	—	0.01		
	16	1-1/2	0.24	0.41	0.22	—	0.007	0.036	0.06	0.08	—	0.00		
	40	1	0.19	0.78	0.24	0.020	0.016	0.045	0.04	0.14	0.030	0.08		
	41	1	0.17	0.70	0.23	0.020	0.015	0.043	0.06	0.17	0.030	0.08		
	42	1	0.19	0.74	0.25	0.020	0.021	0.039	0.10	0.26	0.030	0.08		
	43	1	0.19	0.67	0.21	0.020	0.028	0.039	0.13	0.14	0.030	0.08		
	44n	1	0.22	0.77	0.24	0.020	0.010	0.030	0.05	0.11	0.060	0.08		
	45n	1	0.17	0.77	0.23	0.020	0.017	0.030	0.05	0.11	0.060	0.08		
	46n	1	0.24	0.65	0.24	0.020	0.013	0.043	0.11	0.11	0.030	0.08		
Semikilled	18	3/4	0.16	0.73	0.04	—	0.011	0.033	0.07	0.06	0.000	0.05		
	19	3/4	0.16	0.72	0.05	—	0.013	0.032	0.07	0.09	0.000	0.07		
	20	1	0.17	0.49	0.10	—	0.007	0.030	0.05	0.11	—	0.11		
	22(A)	3/4	0.25	0.50	0.05	—	0.012	0.036	0.04	0.08	—	0.03		
	23	1	0.19	0.49	0.05	—	0.010	0.017	0.05	0.13	—	0.02		
	24	1	0.23	0.45	0.05	—	0.009	0.034	0.04	0.08	—	0.01		
	25	1	0.24	0.46	0.05	—	0.004	0.024	0.04	0.08	—	0.01		
	26	1	0.22	0.45	0.08	—	0.010	0.030	0.04	0.08	—	0.01		
	28	1	0.08	0.32	0.02	—	0.011	0.037	0.04	0.03	—	0.03		
	47	1	0.25	0.45	0.04	—	0.010	0.028	0.05	0.07	0.020	0.02		
	48	1	0.23	0.41	0.04	—	0.006	0.028	0.05	0.07	0.020	0.02		
	49	3/4	0.26	0.39	0.10	0.010	0.020	0.028	0.04	0.10	0.020	0.10		
	50	3/4	0.24	0.39	0.03	0.010	0.030	0.028	0.05	0.13	0.010	0.10		
	51	5/8	0.25	0.36	0.04	0.010	0.020	0.028	0.04	0.10	0.020	0.01		
	52	3/4	0.21	0.42	0.02	0.010	0.020	0.025	0.05	0.16	0.020	0.01		
	53	3/4	0.21	0.41	0.01	0.010	0.019	0.025	0.05	0.13	0.010	0.01		
	54	3/4	0.19	0.44	0.03	—	0.010	0.037	0.05	0.07	0.020	0.01		
	55	3/4	0.21	0.44	0.05	—	0.010	0.037	0.03	0.07	0.020	0.01		
	56	3/4	0.29	0.42	0.07	—	0.010	0.039	0.03	0.07	0.020	0.01		
Rimmed	31	3/4	0.24	0.45	0.02	—	0.013	0.043	0.12	0.08	—	0.21		
	32	1	0.23	0.40	0.01	—	0.010	0.040	0.11	0.06	—	0.33		
	33	3/4	0.27	0.41	0.01	0.009	0.037	0.045	0.15	0.14	—	0.30		
	34	3/4	0.25	0.35	0.02	—	0.008	0.040	0.18	0.11	0.030	0.19		
	35	1	0.24	0.35	0.03	—	0.008	0.039	0.16	0.14	—	0.29		
	57	3/4	0.12	0.36	0.01	—	0.006	0.030	0.05	0.07	0.020	0.20		
	58	3/4	0.11	0.33	0.01	—	0.019	0.035	0.05	0.13	0.010	0.10		
	59	1-1/8	0.19	0.31	0.01	—	0.020	0.028	0.04	0.10	0.020	0.10		
	60	5/8	0.21	0.36	0.01	0.010	0.030	0.028	0.05	0.13	0.010	0.10		
	61	5/8	0.20	0.37	0.01	0.010	0.020	0.025	0.04	0.10	0.020	0.01		
	62	5/8	0.20	0.34	0.01	—	0.008	0.030	0.10	0.10	0.040	0.01		
	63	5/8	0.22	0.37	0.01	—	0.008	0.030	0.10	0.10	0.040	0.01		

Al and Zr (-) <0.005. (N) Laboratory normalized. (n) mill Normalized. (A) Laboratory annealed.
*Code numbers 1 to 35 refer to steels reported in previous investigation[2]; additional steels have been numbered consecutively 36 to 63.

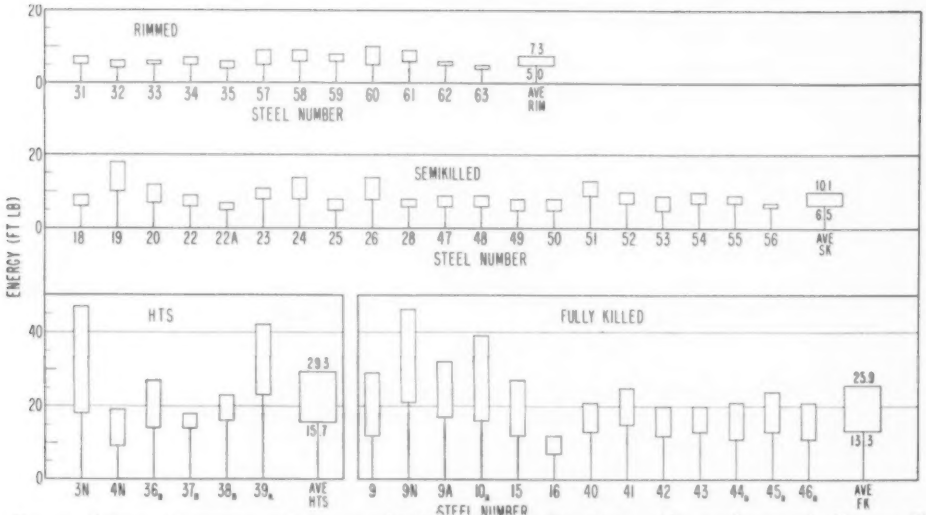

Fig. 6 Range of energy values at which the shear lip along side surfaces of Charpy V specimens vanished

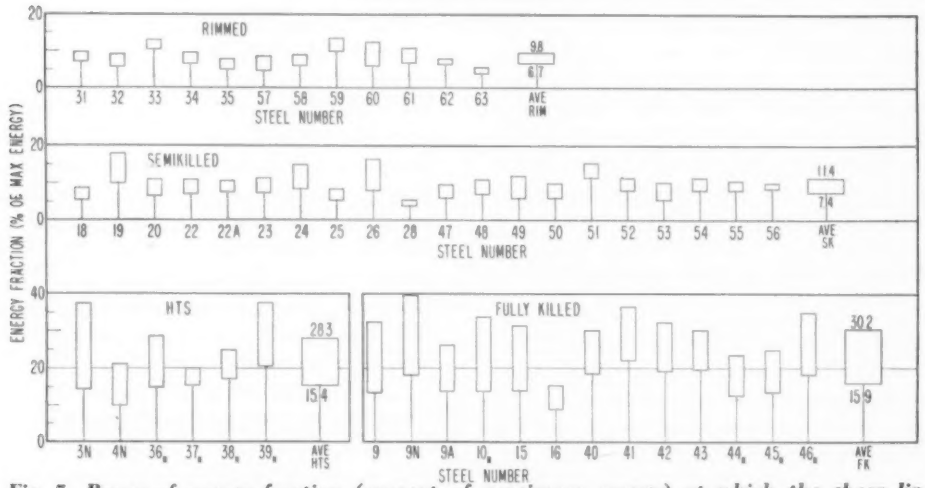

Fig. 7 Range of energy fraction (percent of maximum energy) at which the shear lip along side surfaces of Charpy V specimens vanished

sis, plate thickness and other pertinent details of these steels. The data to be presented relate to specimens oriented with the long axis in the direction of rolling and the notch perpendicular to the plate surfaces. Examination was made of all fractured specimens and the highest temperature at which a sign of shear lip could be observed was noted as well as the next lowest temperature (never more than a 20° F step) which showed no sign of shear lip. The average energy values (position of faired curve) at these two temperatures was then taken as an energy range over which the shear lip was eliminated.

DISCUSSION

Figure 6 depicts the range of energy values at which the disappearance of shear along the side surface was observed for all of the steels which were investigated. Considering the rimmed and semikilled groups individually, it is noted that these two steels display essentially the same energy ranges for the criterion of reference. The fully killed steels, however, show significantly higher energies when the Charpy V side shear is lost than was the case for the rimmed and semikilled steels. These data indicate that for a given condition of crack propagation (loss of side shear) within Charpy V specimens themselves, fully killed steels display significantly higher fracture energies than either rimmed or semikilled steels.

Inasmuch as the fully killed steels for the most part showed higher maximum energy levels, it was of interest to compare the steels on a basis of percentage of the maximum energy obtained for each respective steel. Figure 7 presents these data plotted as an energy fraction (percent of maximum energy). It is apparent that except for minor adjustments which served to bring the various groups closer to an average condition the differences shown in Figure 6 remain unchanged.

Figure 8 depicts the lateral contraction* in the temp-

*NOTE: These data are obtained by measuring the contraction at the base of the notch by means of an optical eyepiece equipped with a stage micrometer calibrated in 0.0001 inch.

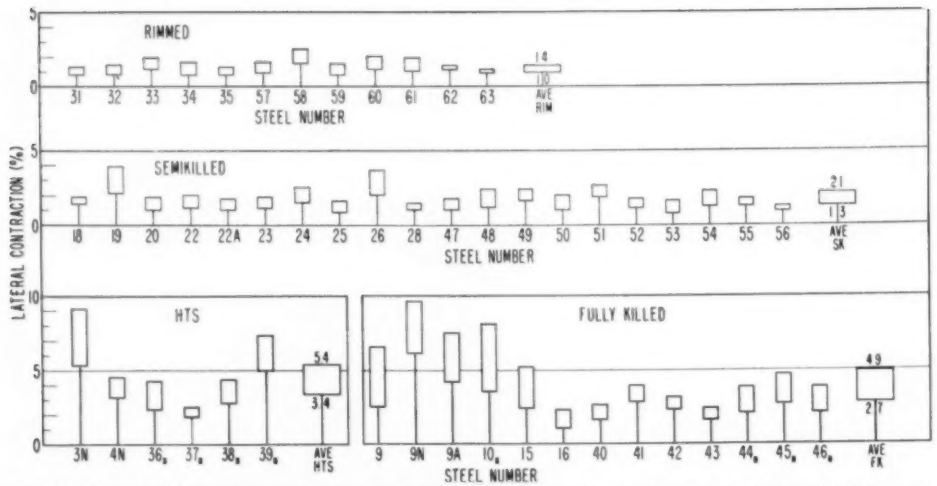

Fig. 8 Range of lateral contraction at which the shear lip along side surfaces of Charpy V specimens vanished

erature range at which the side shear was lost. For the rimmed and semikilled steels, an average lateral contraction of 1 to 2% is developed when the side shear is lost on the V specimens. The fully killed steels show an average of 3 to 5% at the same fracture condition. It is probable that the greater contraction developed by the fully killed steels when the shear lip is lost is responsible for the higher fracture energies.

SUMMARY AND CONCLUSIONS

The National Bureau of Standards correlation of Charpy V data with ship fracture performance has provided a basis for the utilization of notch-bend specimen data for design purposes. This report is concerned with two major questions which have arisen as the result of the success of the National Bureau of Standards investigation:

1. The value of other types of specimens which are in extensive use.

2. Applicability of the National Bureau of Standards correlations obtained for rimmed and semikilled steels to steels of different types.

By a procedure of calibrating the transition features of Charpy Keyhole and Schnadt (coheracic) specimens to the Charpy V energy transition curves, it is demonstrated that the Charpy Keyhole energy transition may be related to conditions of crack initiation and that of the Schnadt specimen to conditions of crack propagation. However, unlike the Charpy V specimen neither the Keyhole nor the Schnadt specimens provide for practical correlation with both aspects of service failures. It is concluded that the Charpy V specimen offers the best possibilities for general use for design purposes.

The Naval Research Laboratory crack starter tests for ship plate steels of the rimmed and semikilled types corroborate the National Bureau of Standards findings in that crack starting is shown to be difficult at temperatures above the Charpy V 10 ft-lb transition and crack propagation likewise difficult at temperatures above the Charpy V 20 ft-lb temperature. However, crack starter tests of fully killed steels show that the initiation and propagation of brittle fractures occurs at much higher Charpy V energy levels, i.e., that the National Bureau of Standards correlation cannot be extended to fully killed steels of the types presently used or considered for ship construction. It is concluded that a criterion of energy which is determined to be proper for a given type of steel may not necessarily apply to a different type.

It is demonstrated that at energy level (of 10 to 20 ft-lb) the Charpy V specimens *per se* show differences in fracture behavior which depend on the type of steel. This finding provides further evidence against the use of an invariant criterion of energy for all types of steels.

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Critical Energy Rate Analysis of Fracture Strength

Mechanical concepts basic to an understanding of fracturing control possibilities and their applicability to large welded structures

by G. R. Irwin and J. A. Kies

IN A RECENT article in this journal[1] the writers discussed how engineering design and materials property controls for the onset of unstable fracturing might be established. The discussion given there was incidental to a more general discussion of fracturing and fracture dynamics. This paper gives a review of the simple mechanical concepts basic to an understanding of these unstable fracture control possibilities and discusses their applicability to large welded structures.

The approach of fracture extension to the unstable or self-fracturing condition can be visualized in terms of the information presented in Fig. 1. The test piece represented in the upper right of this figure is a flat plate with an extending central crack of length, X. For such a test the strain energy release rate, dE/dX, rises steadily with crack length as shown in the lower left of the figure. The self-fracturing structure must include the testing machine and specimen gripping devices. However, if these components are very stiff compared to the test specimen, they will contribute very little strain energy during unstable fracturing and the unstable fracturing process may be thought of as one in which the separation, l, of the grips does not change. Thus the load-extension curve as shown in the upper left of Fig. 1 must become a straight down drop of the load, F, during onset of fracture instability. An instability of this kind can occur with the load-extension curve bending continuously over into a straight down drop as illustrated by Curve *1*. In tests by the writers and their associates, fractures extending in thin sheets of ductile metals have shown this type of approach to instability. When the test piece is a plate of mild steel of average ship steel quality and $^1/_2$ in. or more in thickness, onset of self-fracturing may be quite abrupt with a discontinuity in slope of the load-extension curve as shown by the second case illustrated in the schematic curves of Fig. 1. Ample motivation for the abrupt change from predominately ductile to semibrittle cleavage fracturing may be found in the snapping of tough sections which always accompanies ductile fracturing of mild steel coupled with the sensitivity of that material to impact.

If extensive sections of cleavage fracturing of mild steel plate began and moved along with work rate values, dW/dX much less than the release rate of strain energy, dE/dX, then such instability events would be to a large extent capricious and unpredictable. Such measurements as are known indicate that cleavage fractures of mild steel run with velocities less than half of the transverse sound velocity. Under conditions of validity similar to those for the Hertz theory of impact, the kinetic energy of directed particle motion associated with the changing pattern of strain in the test plate is $(^1/_2)\ (C/C_2)^2$ times the strain energy release times a numerical factor of the order of unity. (Here C is the crack velocity and C_2 is the transverse sound velocity.) Both of these energies are proportional to the same power of the crack length.

If the kinetic energy is represented by the symbol K, then

$$F\frac{dl}{dX} + \frac{dE}{dX} = \frac{dW}{dX} + \frac{dK}{dX} \qquad (1)$$

For a small crack in a large plate both dE/dX and dK/dX are proportional to the length of the crack. The approximate proportionality of K and dK/dX to the square of (C/C_2) becomes ever more exact for representing their dependence upon crack speed as C approaches zero. For the conditions of unstable fracturing as discussed above dl/dX is zero. One concludes that the strain energy release rate and the fracturing work rate must be equal at onset of instability and that they are unlikely to differ widely in magnitude as fracturing continues.

The pattern and appearance of the fracture which occurs in a service or a laboratory case of unstable cleavage fracturing tells the extent to which one may rely in that instance on the near equality of dE/dX and effective dW/dX values as fracturing continues. If dW/dX becomes and continues substantially less

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than dE/dX, the crack velocity increases, the fracture appearance changes and repeated forking or shattering occurs. On the other hand if extensive lengths of cleavage fracturing are observed with little change of fracture appearance and with much less extensive branching than in shatter, then one concludes that a near equality of dE/dX and dW/dX existed all along except close to such points of forking or branching as did occur. In regions of cleavage fracturing such that dE/dX and dW/dX are most nearly equal, as at the start or halting of a segment of cleavage fracturing, calculation or experimental knowledge of dE/dX furnishes our best information of the effective fracturing work rate, dW/dX.

Referring again to Fig. 1, if, when the crack length is X, and the load is F, the testing machine is reversed then F and l decrease while the crack length remains fixed. We may represent at least the upper portions of the unloading curve by the relation

$$dF = M\,dl \qquad (2)$$

where M is the spring constant of the specimen corresponding to the crack length X. The spring constant is a decreasing function of X. For the case of a large structure, M would be the structural modulus to be determined in complicated cases by experiment.

It is useful to note that, for l constant during crack extension, the ratio of F to M should remain approximately unchanged. This is obvious for the case of a brittle crack. Experiments with cracks deepening in notched bars indicate that the constancy of F/M is also not significantly altered by extensive plastic deformation confined to the vicinity of the crack. For semibrittle cleavage fracturing of mild steel the assumption that F/M is constant when l is fixed involves negligible risk of error.

For the conditions of the starting and stopping of unstable fracturing we have

$$\frac{dW}{dX} = \frac{dE}{dX} = \frac{d}{dX}\left(-\tfrac{1}{2}\frac{F^2}{M}\right) \qquad (3)$$

The strain energy, E, is here represented as a negative quantity so that the release rate, dE/dX, will be positive. Since, for F/M constant,

$$\frac{dF}{dX} = -FM\,\frac{d}{dX}\left(\frac{1}{M}\right) \qquad (4)$$

then

$$\frac{dE}{dX} = \tfrac{1}{2}F^2\,\frac{d}{dX}\left(\frac{1}{M}\right) \qquad (5)$$

Having outlined the essential features with the simplifying assumption of fixed grips one may next observe that the stiffness of the loading fixtures is actually of secondary importance. If the grips move during an increment of fracture extension, dX, due to the springiness of the loading fixtures then the drop of the load is less than would occur under fixed grip conditions. The total change of strain energy in the test piece may be thought of as having two parts. One part is the loss of strain energy considered as due to the crack extension, dX, with grips fixed. The second part is the gain in strain energy considered as if produced by elastic extension of the test piece with the crack length fixed. Since it is recoverable spring energy, this second part is separate from and does not directly affect the energy release increment which may expend itself in inelastic work associated with crack extension. The effect of motion of the grips is that such motion tends to maintain the load on the specimen subsequent to the instability point. Thus, whether or not the experiment is done under fixed grip conditions, it is proper to compute the strain energy release rate available for unstable self-fracturing as if the grips were fixed.

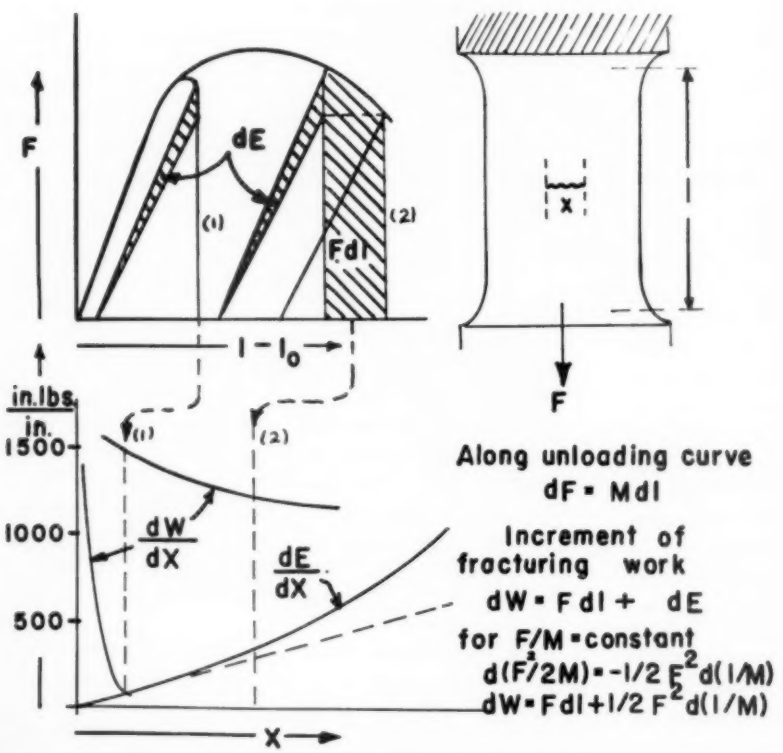

Fig. 1 Schematic diagrams showing continuous and discontinuous types of onset of fracturing instability

The above relations are useful in connection with laboratory fracture tests conducted for the purpose of determining effective dW/dX values in terms of the strain energy release rate at onset of unstable fracturing. Experimentally $1/M$ can be plotted as a function of X by loading trials using specimens precracked by any

convenient means to various crack lengths, X. Other trials can then be made with centrally precracked specimens under condition such that when the crack extends to critical length and then runs on strain energy release across the test piece, the load, F, and the value of X at the start of the instability are observed. Equation 5 can then be used to obtain the effective work rate value governing onset of instability. This procedure[2] has been quite practical at the writers' laboratory in its application to flat plates and plate structures of transparent plastics and to thin sheets of strong light alloys. The results obtained appear to properly represent fracture toughness as affected by temperature, plate thickness and significant variations in fabrication. The measured effective work rates are less for moving than for static starting cracks.

Fracturing work rate values for onset of unstable fracturing in $^3/_4$- and 1-in. mild steel plates may be obtained by the above procedure. However, the testing machine capacity required is beyond the capacity of machines available to the writers. In this paper we shall rely on certain tests using notched bars in slow bending and on supplementary information from centrally notched plate tests done by other groups.

A good indication of the magnitude of the fracture work rate for semibrittle cleavage fracturing of that material is furnished by notched-bend tests conducted at the University of North Carolina during 1947 and 1948.[3] Three-quarter inch thick plates of two materials were used in these experiments. One was a semi-killed steel probably similar to the poorer quality plates tested in investigations sponsored by the Ship Structures Committee. The other material was of similar composition but fine grained and completely killed with aluminum. The former was code labeled "Green" and the Al-killed plate was code labeled "Blue." The tests showed a marked fracture toughness superiority of the Blue over the Green plate material.

The notched-bar fracture tests were conducted in slow bending. The specimens were of square cross section, $^3/_4$ x $^3/_4$ in. outside the notches. Instead of a single notch on the tension side, each of the four sides of the bar at the central test section was notched to a depth of 15% with an Izod cutter. The purpose of this procedure was to reduce the customary lag of the fracture crack at the specimen sides so that the leading edge of the crack was nearly straight across the specimen at all crack depths.

Tests were conducted at a series of temperatures. Fracture work rates for slow ductile fracturing were obtained in accordance with the equation

$$\frac{dW}{dA} = R\frac{d\theta}{dA} + \frac{dE}{dA} \qquad (6)$$

where R is the torque applied to the specimen, θ is the over-all specimen-bend angle, and $Rd\theta$ is the increment of work done by externally applied forces on the test specimen during the fracture extension, dA. Here again the positive sign on dE means a release of elastic energy from the specimen. A series of fracture area increments, dA, were applied and were marked by staining, and measured after complete fracture of the test section. The unloading program after each increment of fracturing permitted measurement of specimen strain energy. The strain energy in the balance of the system was a known function of the applied load. Thus by plotting strain energy against fracture depth it was possible to determine dE/dA experimentally. The assumption that the ratio of the bending moment, R, to the specimen spring constant was an invariant of crack depth was not used. However, recent studies of the data[3] by the writers indicate the assumption would have been valid through the whole range of crack depths excluding the extreme portions, the portion where the crack was just forming and the final portion where closure of the back notch brought in new effects of uncertain magnitude.

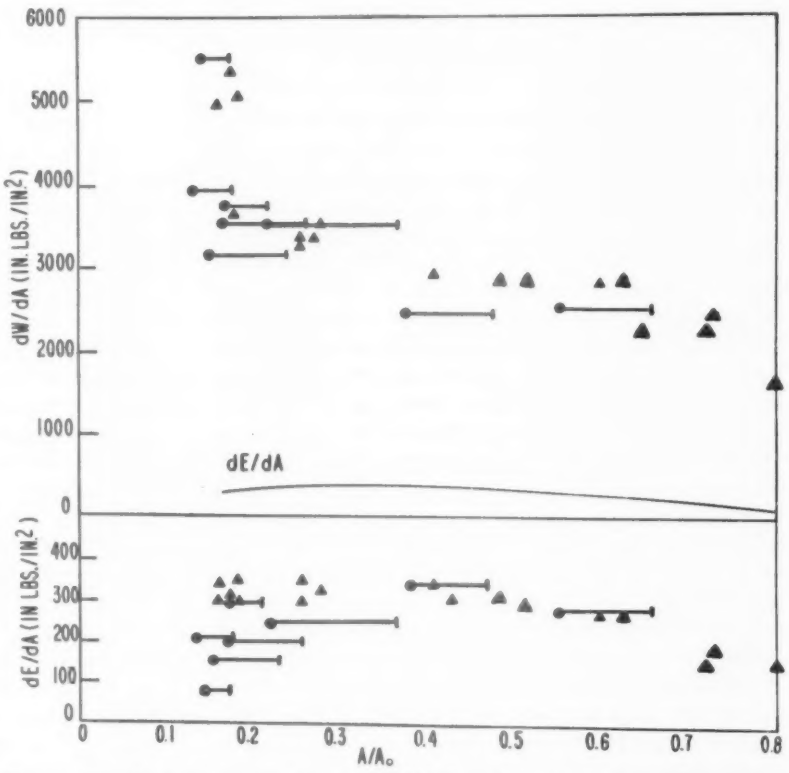

Fig. 2 Ductile fracture work rates (dW/dA) and strain energy release rates (dE/dA) for progressive fracturing in bending of $^3/_4$-in. mild steel bars notched on all four sides. Short verticle bars in lower graph are equivalent to measurements of effective work rates for onset of semibrittle cleavage fracturing. Data are from Shearin, Trimble and Rogers[3]

Figure 2 shows the comparison of ductile fracture work rate and dE/dA values for these tests. It is at once apparent that the advantage of having to apply smaller forces in notched bending in order to fracture a section of the plate is obtained at a considerable sacrifice. Instead of having available a steady increase of dE/dA values against which the fracture toughness of the material might be measured, this test provided only values in the range of 200 to 350 psi. Unless a material possessed an effective work rate fracture toughness as small as this range of values, then no fracture instability occurred. In a comparison of materials by such a test the most obvious result found, with a series of decreasing temperatures, is the temperature at which the effective work rate for unstable fracturing becomes low enough to show fracture instability. The existence of a progressively increasing strain-aging embrittlement as the fracture deepens makes the crack depth at onset of fracture instability somewhat uncertain. The data of Fig. 2 is for the Green plate. The abscissa used is the ratio of fracture area, as revealed by the staining technique, to the total area of the section severed when the fracture is completed.

Results from tests of several specimens at each of three temperatures, 76, 90 and 100° F are superimposed on Fig. 2. At the highest temperature the last fracture segment was cleavage in only two of seven specimens. At the lowest temperature all fractures were completed with cleavage. The plotted points are placed at the middle of the fracture band which was used to determine each point. Where the fracture band terminated with onset of cleavage this position is marked by a short vertical bar joined to the "middle of the band" point by a horizontal line. Even though the ductile fracture work rate values are depressed in these tests by side notching they are clearly larger by a factor of about ten than the effective work rate values characteristic of semibrittle cleavage fracturing which are the points joined to horizontal lines in the lower graph of the figure. For this particular slow-bend test the Green plate might be said to have a transition temperature of 85° F while the Blue plate had a transition temperature of 25° F. There was, in addition to this temperature difference, an average dW/dA advantage for the Blue plate of about 50 in. lbs/in.^{2} There is no indication in these tests that effective work rate values characteristic of a particular form of fracturing—for example, slow ductile as compared to semibrittle cleavage—undergo large changes as the temperature is reduced. These work rate values are, however, known to be influenced by plate thickness, orientations of the fracture relative to rolling direction and damaging types of heat treatment.

Reference may now be made to the results of several investigations in which centrally notched plates of mild steel were used. One well-known series of such tests was performed at the University of Illinois[4] using plate widths ranging from 12 to 72 in. The initial slot, with its jeweler's hacksaw-cut ends, in each case had a length of one-fourth of the plate width. Values of dE/dA at onset of fracture instability were estimated from the published data and showed a steady increase with the test plate width. A quantity with the dimensions of stress, $(1/B)$ (dE/dA) where B is plate width, may be compared for the various sizes as an indication of the effect of lateral dimensions upon the fracture strength. Such a comparison shows a normal size effect, that is, a steady decrease of moderate amount with increase of B. However, this decrease of $(1/B)$ (dE/dA) with increase of B is much less than would be required for (dE/dA) to remain constant with increasing B. Intuitively one would expect the effective cleavage fracture work rate to approach a constant value with lengthening of the starting crack. It is probable that careful study of experimental work already done in various tests of large steel plates and plate structures would reveal some firm evidence on this point. Currently one can only say that an increase of cleavage fracture work rate with lengthening of the crack beyond a starting size of five times the plate thicknesses appears most unlikely. All of our model experiments in which work rates for "saw cut" and natural cracks were compared have shown larger fracture work rates in the case of the "saw cut" starting cracks. Thus large values of dE/dA at instability which one can obtain from the wide plate tests of ship steels do not represent amounts of fracture toughness which can be counted on to resist cleavage fracture propagation continuing from natural cracks.

By confining attention to 12-in. wide plate tests of the University of Illinois[4] and at Swarthmore[5] one can select cases in which a thumbnail of ductile fracture preceding onset of cleavage indicated that the operative (dE/dA) driving energy was neither far below nor far above the critical value for onset of cleavage fracturing. Such instances of fracture instability of this nature which the writers could find indicated a cleavage fracturing work rate of about 200 in. lbs/in.^{2} This cleavage fracturing work rate appeared to be insensitive to temperature in the range of room temperature to −40° F.

The concept of a cleavage fracturing work rate value for plates of mild steel, as discussed above, is not independent of events which precede onset of cleavage. In the extreme case of onset of cleavage at the root of a notch from one or more ductile fracture origins of inconspicuous size, the computed dE/dA value at onset of instability is usually quite large, for example 800 in. lbs/in.^{2} in the 72-in. wide plates at the University of Illinois. Three other cases may be recognized. These are (*a*) cleavage fracturing starting from a "thumbnail" of ductile fracture at the root of a notch or from a section of ductile fracture of any length in which general plastic deformation was suppressed by side notching, (*b*) the onset of cleavage for a slowly extending crack under fatigue or repeated load conditions and (*c*) a continuation of cleavage fracturing when a cleavage crack is moved quickly into a plate subjected to tension.[6] It seems probable that measurements made under conditions corresponding to (*a*) and (*b*) will give similar cleavage fracture work rate values. From ex-

perience with other materials it might be anticipated that condition (*c*) would result in moderately smaller cleavage fracture work rate values. Condition (*c*) corresponds in service failures to sudden fracturing of a flawed region.

A fatigue crack ordinarily advances by sudden short jumps. The instability criterion applies to the start of each jump and for this case[7] dE/dA has been calculated to be as low as 35 in. lbs/in.^{2} for a very small region in the immediate vicinity of the fatigue crack head. Intermittent stopping presumably occurs because the fatigue damage is localized and dW/dA is much more than 35 in. lbs/in.^{2} beyond this region.

When the crack length at instability is less than one-third of the plate width and the equivalent length of the specimen, allowing for springiness in the grip and machine, is more than twice the plate width a simple method can be used for estimating values of dE/dA. The procedure shown here is in agreement with the equation used by Griffith and is strictly accurate for an infinite plate. For illustration consider the result of one of the Swarthmore tests. The test was made with 12-in. wide plates of $^3/_4$-in. steel having a central notch 3 in. wide. The nominal stress, σ, was 32,000 psi. We assume the strain energy relieved by the central slot plus its cracked extensions is just the strain energy which would be contained in an ellipse having the separation of the crack tips as its minor axis, twice this length as its major axis, and located in a position where the stress is the nominal stress. Thus, if X is the crack length,

$$\frac{dE}{dA} = \frac{1}{t}\frac{dE}{dX} = \frac{1}{t}\frac{d}{dX}\frac{\pi X^2 t}{2}\frac{\sigma^2}{2Y} \qquad (7)$$

where Y is Young's Modulus and t is the plate thickness. For $X = 3.5$ in.

$$\frac{dE}{dA} \cong 200 \text{ psi} \qquad (8)$$

Irwin and Kies published a more exact method for making this calculation.[1] This working formula has been simplified[2] and is

$$\frac{dE}{dA} = \frac{\pi F^2}{BYt^2}\frac{y(2 + y^4)}{(2 - y^2 - y^4)^2} \qquad \text{where } y = \frac{x}{B} \qquad (9)$$

B = width, t = thickness and Y = Young's Modulus. F is the load, decreasing as y increases, on the fixed grips when the relative crack length is y. This formula is independent of specimen length and applies to the onset of instability. Certain dynamic effects are length dependent but are not discussed here. It should be kept in mind that the above formulas apply strictly to simple plates under tension. In the case of major structures the simple formula of eq 3 would be used and the structural modulus M and dM/dX would not necessarily be calculated but might be determined experimentally under service loading conditions. If the measured structural modulus turned out to be less than the calculated one then an unexpectedly high energy release rate would be possible.

Both for its practical aspects and as a means for obtaining a long starting crack while at the same time avoiding excessive plastic deformation, the extension of a crack to critical length by fatigue or repeated loading deserves attention.

Indication of what may be done along these lines is furnished by the Cornell University ship plate steel fatigue tests.[8] These tests do not, actually, exhibit results in which the unstable fracture length in the sense of complete fracturing was attained. If we assume that each test, in which well-developed cracks appeared, was carried to the point where the speed of extension of the crack, say per 1000 cycles, indicated to the test operator serious danger of a quick break, then the dE/dA values for these crack lengths represent limiting values of practical interest. The tests of simplest geometry were with $^3/_4$-in. plates of 17 in. width containing a 4.25-in. diam central hole. Cracks extending 1 to 2 in. to each side of the hole were obtained in 20,000 to 100,000 cycles using a nominal stress of 22,500 psi and in nearly one million cycles for a nominal stress of 15,000 psi. More than half the test time was required to get any kind of a crack started. Estimates of dE/dA were made by several rough approximation methods. All of these computed values were in the range of 150 to 400 in. lbs/in.^{2} The ability of ship steel plate to resist extension of fairly long cracks with effective dE/dA values in the range of 150 to 400 in. lbs/in.^{2} suggests that cleavage fracturing of mild steel plates requires dE/dA values which are far from vanishingly small. Apparently, for $^3/_4$-in. mild steel plates, more than 100 in. lbs/in.^{2} of fracture must ordinarily be supplied from the strain energy field.

Another notable fact which carries a similar message is that mild steel cleavage fractures have been observed to stop in plates subjected to tensile stress in the range of 10,000 to 15,000 psi.[6] The expected mechanics of having a fracture change from an unstable to a stable condition relative to self fracturing on released strain energy does not differ greatly from the reverse transition as represented in the experiments discussed above. Although information available to the writers does not permit calculation in this paper of effective dW/dA values from fracture arrest data, the observations discussed in Reference 6 are not inconsistent with work rate values of 100 in. lbs/in.^{2} or more.

Estimates along the lines discussed above using a dW/dA of 200 in. lbs/in.^{2} indicate that if the nominal stress in a structure of mild steel plates never exceeds 30,000 in. lbs/in.^{2} then a crack forming and moving out into a plate of this structure should not go unstable until it has developed to a length of 4 in. The critical length for 15,000 in. lbs/in.^{2} would be four times as large. Cleavage fracture origins as large as this are not often found because the starting crack length can be produced in large welded structures in so many ways other than by creep or by growth in fatigue. Most of these have to do with poor weldments and the residual stresses associated with welds. Efforts to find out more about the seriousness of various kinds of flaws are in progress at several places. In order that the information from these

studies may be helpful in more than a qualitative sense, it is desirable that the experiments be designed so as to show the strain energy release rate considerations applicable either to the start or to the arrest of unstable fast fracturing. The same remark applies to studies of transition temperatures. In the latter case so much has been done with standard impact tests that an effort might be made to correlate results of these standard impact tests with some test capable of furnishing effective dW/dA values at crack lengths appropriate to specific applications. A centrally notched plate in fatigue is an example of one kind of measurement which might be employed for this purpose.

Several ways suggest themselves of using dW/dA values in connection with estimating danger of brittle fracture in large structures of mild steel plate. For example where a welded connection between two plates runs parallel to the direction of greatest tension, cracks to either side perpendicular to the weld and extending through the heat-affected zone might be considered to indicate a probable starting size. Allowing something for unnoticed extension of such a crack during periods of stress and temperature variation and assuming this happens in poor quality ship plate, a calculation can be made based on, say, a 3-in. long starting crack and an effective dW/dA of 150 in. lbs/in.[2] For this situation it should not be far from correct to take

$$150 \text{ psi} = \frac{\pi \text{ (3 in.) } (\sigma^2)}{2 \times 30 \times 10^6 \text{ psi}}$$

Thus we would find σ equals about 30,000 psi as a condition for fracture instability. It has been suggested that brittle fractures of welded ships might be eliminated if no stresses large enough to cause yielding were permitted in the structure. The suggestion appears to be quantitatively appropriate for the starting crack situation just described.

If the weld parallel to the tension direction is joined by a crosswise weld coming in from one side, the situation is somewhat more alarming because we do not know how much of the crosswise weld participates virtually or actually as part of the starting crack. It may be a few inches or as much as a foot. If the latter is the case then a nominal stress of less than half of the material yield strength is a dangerous condition.

Unless some limitation can be placed upon the starting crack sizes which have fair probability of occurrence the stress limitations for safety against unstable fracturing become quite unreasonable. A logical conclusion is that inspection procedures might furnish upper bounds on the lengths of the starting cracks which need to be assumed as potentially present in the structure during its load time history. Granting that we have or can find out the critical strain energy release rates for various cracks and flaws then one can estimate their seriousness relative to one another and relative to the structure containing them. The inspectors can then be told what flaws are not tolerable and the design drawings can be checked in a realistic way for estimating danger of unstable fracturing. The checking procedure would be to suppose cracks of the maximum nonobservable length to exist in the worst location of each region of high stresses. One would then calculate dE/dA for each and compare with whatever appropriate effective dW/dA values are known.

The proposals listed above appear to be direct applications of certain information about fracturing which has emerged in recent years. It is realized that practical construction difficulties associated with large welded structures make a situation far from ideal for theoretical considerations, that inspection of some areas may be inconvenient, and that the workmen never cease from producing unpredictable flaws. However, it is believed the introduction into engineering design of rational quantitative procedures for control of unstable fracturing will, nevertheless, have many beneficial effects.

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Electrode Standard*

The new Czechoslovakian standard No. 420150, which was put into effect Jan. 1, 1952, replaced the old German standard No. 1913 which had become obsolete. The new standard divides coatings into: light stabilizing; organic, rutile, rutile-organic, neutral, basic, oxidizing, acid and special. Both dipped and extruded coatings are considered. The standard lists electrodes for the following applications:

(*a*) For welding mild and low-alloy steels.
(*b*) For welding corrosion and heat-resistant steels.
(*c*) For surfacing.
(*d*) For welding aluminum, copper and their alloys.

An example of the information contained in the new standard may be quoted for classes 7 and 8 in the 67,000 psi grade. Class 7 has an extruded thick neutral coating (6020) suitable for use on pressure vessel and pipe steels and on structures designed for fatigue. Straight polarity and alternating current may be used. The minimum mechanical properties are: yield strength = 51,000 psi, tensile strength = 67,000 psi, elongation = 23% in 5 diameters, notch impact value = 8 mkg/cm^2. The weld metal contains 0.10 C, 0.70 Mn, 0.15 Si, 0.05 max P, 0.04 max S. Class 8 has an extruded, thick lime coating (6015) suitable for pressure vessel and pipe steels, etc. Reverse polarity is used. The mechanical properties are the same as Class 7 except that the minimum notch impact value is 13. The weld metal contains 0.08 C, 1.40 Mn and 0.50 Si.

* This was prepared by Jan Ruzek from the Czech magazine *Svaranie*, October, 1953.

Evaluation of Superheater Materials for High-Temperature Steam

Experimental installation for evaluation of superheater materials in contact with steam at temperatures between 1100 and 1500° F

by Bela Ronay and W. E. Clautice

FOR more than fifteen years the American Society of Mechanical Engineers has actively sponsored research on the generation of steam at high temperatures. The critical section of the steam generator is the superheater where metal temperatures may exceed steam temperatures by 150° F. A series of articles published in the *Transactions* of ASME between 1942 and 1946 presented results of experimental work on the corrosion of alloy steels by high-temperature steam. This work was conducted at Purdue University on low-pressure steam at 1100 to 1800° F for periods of exposure up to 2000 hr.

In 1948, the ASME Research Committee which had guided the work at Purdue University was reorganized as the ASME Research Committee on High-Temperature Steam Generation. This reorganized committee evolved a plan for an extensive investigation of alloys suitable for superheater service within the temperature range of 1100 to 1500° F. The Committee is composed of representatives of manufacturers of steam power generating equipment and users of such equipment, including the U. S. Navy. Funds for construction of the test apparatus and the performance of the investigations are being contributed by interested manufacturers and users of steam generating equipment. The contribution of the U. S. Navy is the design and fabrication of the test racks and all auxiliary equipment required to expose the alloys selected for the test to steam flow at various temperature levels and time periods. Materials and accessories of this installation are financed from committee funds. The installation will provide means for passing steam at various temperature levels through several test racks, each of which will contain a number of alloys. The design and fabrication of this test installation was assigned to the Welding Laboratory of the U. S. Naval Engineering Experiment Station. Design of the installation was reviewed by the Fabrication Sub-Committee of the ASME Research Committee on High-Temperature Steam Generation.

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OBJECTIVES OF INSTALLATION

The objectives of the program of the Committee on High-Temperature Steam Generation were stated in their progress report, dated July 31, 1950, as follows:

"Determine for a number of selected alloys at stated temperatures the following:

"1. Nature, thickness, permanence and thermal conductivity of oxide films on steam swept surfaces.

"2. Their resistance to gases encountered in commercial services.

"3. Their metallurgical stability over long periods of time.

"4. The effects of repetitive thermal shock."

The purpose of the installation presented in this paper is to provide means for investigating the alloys selected for the test as regards items 1, 3 and 4 above. It is intended to accomplish this by exposing test specimens consisting of ferritic and austenitic steel and nonferrous alloy tubing to steam flow at several steam temperatures for varying periods. In the steady state of operation, the pressure in the system will remain constant. Groups of tubes in each test rack will be removed at prescribed intervals. These will be forwarded to Purdue University, where, using test apparatus designed and built for this purpose, they will be examined to evaluate the change of their heat transfer characteristics. In addition, portions of the tubes will be subjected to physical and chemical tests and metallographic examination.

The results of the above tests will be the basis of conclusions concerning the suitability of the various alloys tested as superheater tube materials.

PLAN OF THE STEAM EXPOSURE INSTALLATION

The test apparatus is designed for a pressure level of 2000 psi. This is available at the Philip Sporn Power Plant, West Virginia, where the test installation will be erected.

Basically, the installation will consist of five test racks: one for a steam temperature of 1100° F containing ferritic alloy tubes, two racks for 1200° F steam temperature—one of these containing ferritic tubes and the other austenitic and nonferrous tubes—and one rack each at 1350 and 1500° F steam respectively, containing austenitic and nonferrous tubes. The five racks will operate in series, passing 1000 lb of steam per hour at 2000 psi. Each test rack will contain an inlet and outlet manifold. The tube specimens will be welded into these manifolds and, therefore, will be in parallel within each test rack. Steam at the Philip Sporn Plant will be available at 950 to 1000° F. To permit operation of the five test racks at the above given temperature levels, auxiliary apparatus will be employed to provide steam for each rack at the temperature specified for it, as indicated in Fig. 1.

Two types of auxiliary devices are to be employed for this purpose. First, in the interest of better economy in operation, the heat energy contained in the steam discharging from the 1500° F test rack will be extracted in three successive stages. This will be accomplished by the use of three heat exchangers located as indicated in Fig. 1. Second, five "presuperheaters" are provided, one before each test rack. The role of the "presuperheaters" is to raise the steam temperature to each of the

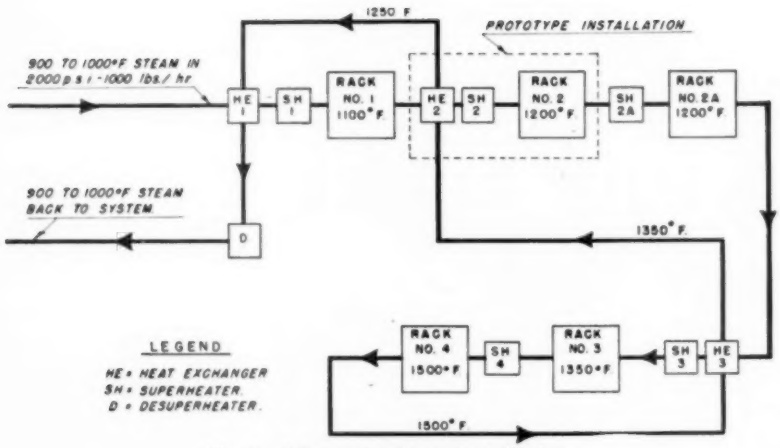

Fig. 1 Schematic of test installation

four levels at starting and to maintain these temperature levels in the steam entering the respective test racks during operation, thereby compensating for losses inherent in such a system. As shown in Fig. 1, all the above units will be in series. The last heat exchanger, marked in Fig. 1 as HE #1, will deliver the steam to a desuperheater before it is returned to the distribution system of the power plant.

Accordingly, on having reached steady state condition, the test installation will function as follows:

Steam entering from the feed line at 950 to 1000° F will pass first through Heat Exchanger No. 1 where its temperature will be raised to near 1100° F. From this heat exchanger it will enter Presuperheater No. 1, where it will be controlled at 1100° F. Within Test Rack No. 1, the 1100° F steam temperature will be maintained by radiant heaters located to prevent radiation losses from the specimen tubes. From Test Rack No. 1 the steam will pass through Heat Exchanger No. 2 and Presuperheater No. 2 where its temperature will be raised to 1200° F. Thence the steam will enter into Test Rack No. 2 where the 1200° F steam temperature will be maintained by the means described for Test Rack No. 1. Since Test Rack No. 2a will be operated at 1200° F also, there will be only a presuperheater between it and Test Rack No. 2. From Test Rack No. 2a, steam will pass through Heat Exchanger No. 3 and Presuperheater No. 3 where its temperature level will be raised to 1350° F. In Test Rack No. 3 the entering steam temperature of 1350° F. will be maintained as given for the others mentioned above. Between Test Rack No. 3 and the final No. 4 is Presuperheater No. 4 where the steam will be heated to 1500° F, which temperature will be maintained in Test Rack No. 4. From the latter, the steam will be directed successively through Heat Exchangers 3, 2 and 1, when it will be piped to the desuperheater mentioned above.

SELECTION OF MATERIALS

Selection of alloys considered suitable for each of the four temperature levels was guided by the following criteria:

(*a*) The comparison of the tube working stresses with the stresses required to produce a creep rate of 0.02% in 1000 hr at the temperature levels considered.

(*b*) The comparison of the tube working stresses with 80% of the stress necessary to produce rupture in 25,000 hr at the specified temperature levels.

From among the alloys produced commercially for high-temperature steam service and a few others not in conventional use, those found in Table 1 were selected for consideration.

For the purposes of the test, the tube size and wall thickness of the test specimens were selected as 2-in OD and 0.500 in., respectively. The working stress was determined for tubes of the above dimensions and for a constant steam pressure of 2000 psi from the formula,

$$s = \frac{PD}{2t}$$

where

s = stress, psi
P = steam pressure, psi
D = *inside* diameter, in.
t = tube wall thickness, in.

From the above formula, a working stress of 2000 psi is indicated in all specimens of the above dimensions, while steam pressure is constant at 2000 psi.

From the list in Table 1, materials were selected for the various temperature levels on the basis of their creep and stress rupture values in accordance with the criteria given in (*a*) and (*b*) above.

The plan of distribution of alloys in the several racks is given in Table 2.

DESIGN OF SUPERHEATER RACKS

The five superheater racks are identical in design. Essentially, each rack contains 30 specimen tubes, each 2 in. OD, 0.500-in. wall thickness and 42 in. long.

Table 1

	Chemical analyses									
Alloy type	*C*	*Mn*	*Si*	*Cr*	*Ni*	*Mo*	*Va*	*Ti*	*Cb*	*Cu*	*Fe*
SA213											
T22	0.15 max	0.3–0.6	0.5 max	2.0–2.5	...	0.9–1.1	...	...	...	...	Rem
T21	0.15 max	0.3–0.6	0.5 max	2.75–3.25	...	0.8–1.0	...	...	...	...	Rem
T5	0.15	0.3–0.6	0.5 max	4.0–6.0	...	0.45–0.65	...	...	...	...	Rem
T16	0.12 max	0.3–0.6	0.5 max	4.0–6.0	...	0.45–0.65	...	0.60–0.70	...	...	Rem
T13	0.15	0.3–0.6	1.0–2.0	4.0–6.0	...	0.45–0.65	...	...	...	...	Rem
T9	0.15	0.3–0.6	0.5–1.0	8.0–10.0	...	0.9–1.1	...	...	...	...	Rem
AISI											
304	0.08 max	2.0	...	18.0–20.0	8.0–11.0	...	...	...	...	...	Rem
347	0.08 max	...	...	18.0	10.5	...	...	...	0.8	...	Rem
321	0.08 max	...	...	18.0	9.5	...	...	0.45	...	...	Rem
316	0.10 max	2.0–3.0	0.75	16.0–18.0	10.0–14.0	2.0–3.0	...	...	...	...	Rem
310	0.15 max	2.0 max	0.75	25.0	20.0	...	...	...	...	...	Rem
309	0.08 max	2.0	...	22.0–24.0	12.0–15.0	...	...	...	...	...	Rem
Armco 17–14 Cu-Mo	0.08	...	...	17.0	14.0	3.0	...	0.3	0.5	3.0	Rem
Timken 16-25-6	0.10	...	...	16.0	25.0	6.0	...	...	...	...	Rem
Inconel	0.20	0.8	2.0	14.0	78.0	...	...	...	...	0.25	Rem
Incoloy	...	...	...	20.0	35.0	...	...	...	...	...	Rem
GE-Chrome moly-Va	0.15 max	...	0.10–0.35	0.8–1.2	...	0.8–1.1	0.15–0.35	...	...	...	Rem

The tubes are arranged in the vertical position spaced equally on the periphery of a 34-in. diam circle. To facilitate removal and replacement of tubes, a rack is made into three 120-deg removable segments, each consisting of the 10 specimen tubes to be tested. Each rack is provided with three spare segments. This arrangement allows segments to be removed and replaced by spares periodically so that individual segments of the 10 specimen tubes in each rack are subjected to steam flow for 6, 12, 18, 24, 30 and 36 month periods. Each segment contains a top and bottom manifold; these in turn are connected to the feed and discharge mains, respectively, by three connecting tubes. The rack is shown in Fig. 2 and Fig. 2*A*, a drawing and a photograph, respectively. The manifolds are 2-in. OD, 0.500-in. wall tubing and the connecting tubing is of 1-in. OD, 0.250-in. wall thickness. The materials of these manifolds were selected to meet the respective demands of the temperature levels of the various racks. The connections between the manifolds and the specimen tubes are goosenecks made of 0.625-in. OD, 0.187-in. wall thickness tubing of the same material as the manifolds or headers. The direction of steam flow through the specimen tubes is from the bottom upward. To prevent clogging of the steam inlet at the bottom by eventual scale accumulation, the goosenecks join the specimen tubes $1^1/_2$ in. above the bottom. The steam outlet from the specimen tubes into the top goosenecks is through a butt joint between the top ends of the specimen tubes which are swaged down to size and the goosenecks. Thus, the design of the goosenecks at the bottom differs from that at the top. Both the top and bottom goosenecks are of alternating contour but of equal length in each position. This arrangement provides the clearance needed to weld the joints between goosenecks and headers, and also eliminates a continuous line of holes weakening the headers.

As shown in Fig. 2 and Fig. 2*A*, baffle plates separate the lengths of the specimen tubes into two separate portions. The portions of the tubes between the baffle plates near the top of the rack will be exposed to periodic thermal shock by automatic activation of a simulated soot blower which impinges air upon the tubes. The superheater racks will be enclosed within a structure of insulating blocks, whose arrangement resembles that used in electric muffle furnace construction. Electric resistance heater elements are fastened to the vertical inner surface of the insulated enclosure to furnish a heat input sufficient to overcome radiation losses from the specimen tubes. To assure even heat distribution, an austenitic steel muffle is provided between the heating elements and the specimen tubes.

Standard joints are used in the construction of the superheater racks, namely, the

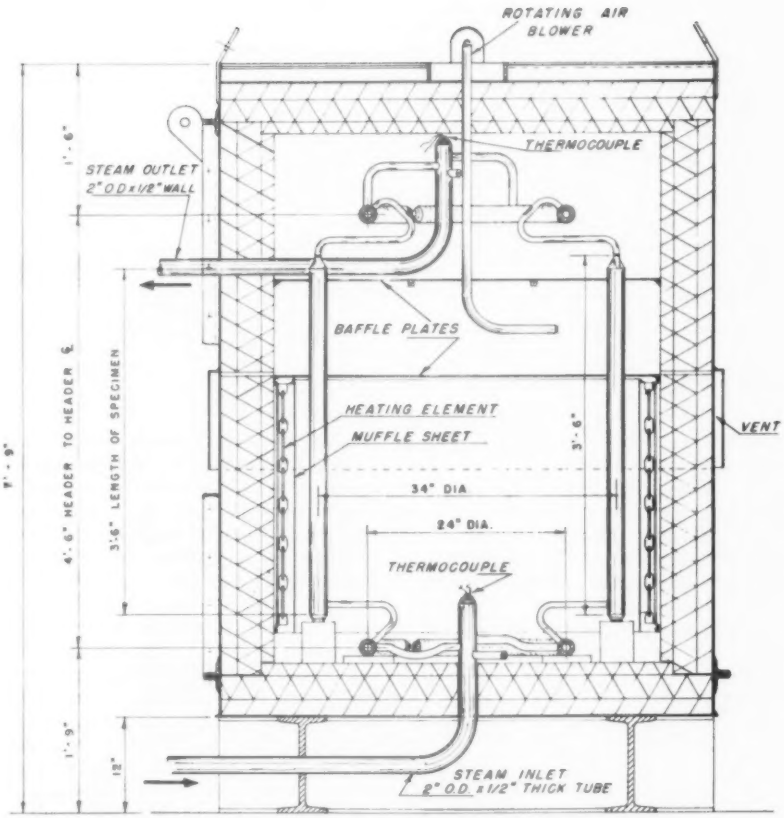

Fig. 2 Typical section of test rack

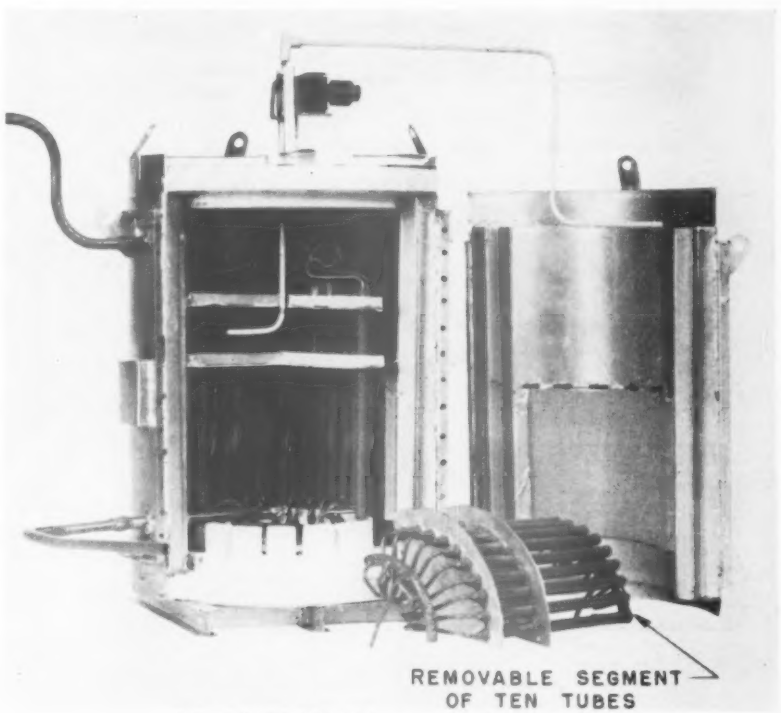

Fig. 2A Model of the superheater test rack

Table 2

Rack No. 1 1100° F	*Rack No. 2 1200° F*	*Rack No. 2A 1200° F*	*Rack No. 3 1350° F*	*Rack No. 4 1500° F*
SA213T22	SA213T22	AISI 304		
SA213T21	SA213T21	AISI 347		
SA213T5	SA213T5	AISI 321		
SA213T16	SA213T16	AISI 309		
SA213T13	SA213T13	AISI 316		
SA213T9	SA213T9	AISI 310	Same as Rack 2A	
GE Cr Mo Va	Welded T22*	Armco 17-14 Cu Mo		
Welded T22*	Welded T21*	Timken 16-25-6		
Welded T21*	Welded T5*	Inconel		
Welded T5*	AISI 347 vs. SA213T16†	Incoloy		

* Conventional butt joint.
† Welded composite joint.

butt, tee and socket types. Details of the butt joints are shown in Fig. 3. Because of the high pressure in the system, the butt joints must be full wall thickness, and preferably free of the stress raisers present in the conventional types of tube joints containing backing rings. Also, the presence of backing rings would cause throttling of steam flow, particularly in the 0.625-in. diam joints between the swaged ends of the specimen tubes and the goosenecks. The use of the proprietary joints shown in Fig. 3 provides smooth interiors without reducing the bore diameter. The joints are assembled with ceramic backing prepared in accordance with the design shown in Fig. 3. The ceramic backing is composed of sharp sand procured in accordance with Bureau of Ordnance Specification 50-S-2, No. 20. A cellulose acetate binder air hardening in 15 to 30 min, is used to bond the loose sand into the desired geometry to serve as backing.

Welds at the mid-lengths of the previously described "welded" specimen tubes will be made using the above butt joint design. The ceramic-backed joints are metal arc welded using the conventional procedure for pipe welding, except that in depositing the first pass the welder must observe that the hole formed by remelting the two tube ends remains of constant area, approximately the diameter of the electrode used. If the hole appears to diminish in size, the rate of progression must be reduced; if the hole diameter tends to increase, the welder shifts the electrode on the 45-deg bevel side of the joint. This action provides time for the weld pool to solidify so that on resumption of deposition the hole diameter may be kept under control. After the first pass has been completed, welding the second and subsequent passes is performed in the conventional manner. Cleaning the slag off the first pass with a chisel is sufficient to cause the collapse of the ceramic backing, whose binder burns out during the deposition of the first pass. The collapsed lining then resumes its original form of fine sand and is removed by air blast through the open bottom of the specimen tubes. These joints are assembled for welding in a jig which provides alignment and approximately $^1/_{16}$ in. separation of the sand faces for those joints, which by reason of the properties of the materials must be preheated before welding. During preheating, the tubes expand and the above given separation prevents crushing of the ceramic backing. The $^1/_{32}$-in. overhang of the ceramic backing facilitates remelting of the tube ends by providing space for forming a shallow interior bead. A section of a composite butt joint, wherein austenitic and ferritic tubes are united over ceramic backing, is shown in Fig. 4.

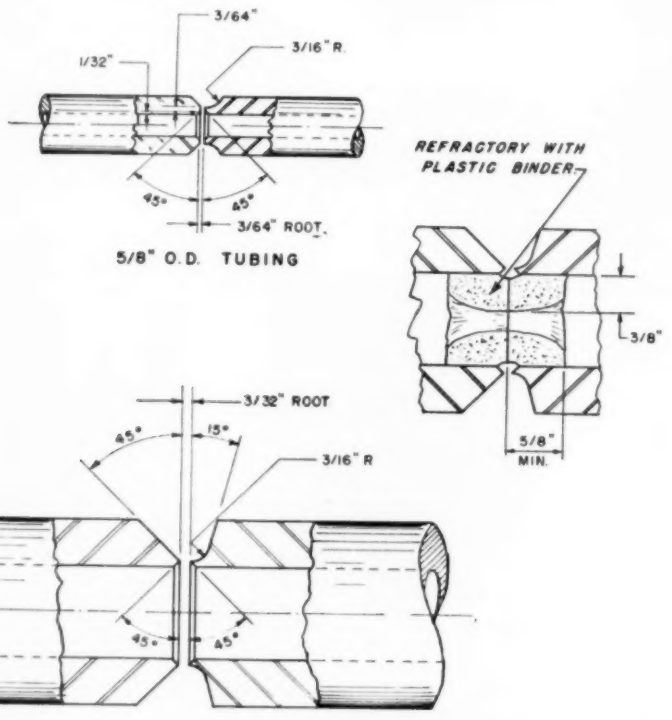

Fig. 3 Butt joint design, nonmetallic backing

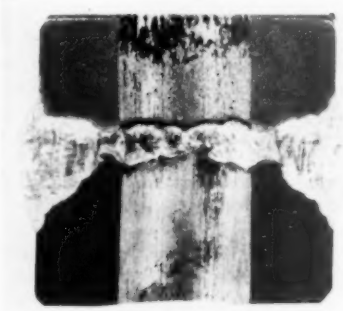

Fig. 4 Butt joint macrograph of composite joint (austenitic vs. ferritic steels). 2 in. OD tubing

TEE JOINTS

Details of the tee joints are shown in Fig. 5 and a macroetched section in Fig. 6. This design is different from that developed for use in naval construction. The approved tee joint used by the Navy and also by many industrial fabricators consists of a solid forging, which is bored out after the joint is completed. The forging is then tied into the line by a conventional butt joint. The lack of clearance and the intricacy of the contour of the goosenecks made it necessary to develop a joint whose fabrication was practicable even though the design does include a potential stress raiser at the root of the joint. However, in view of the limited service life of this installation and that

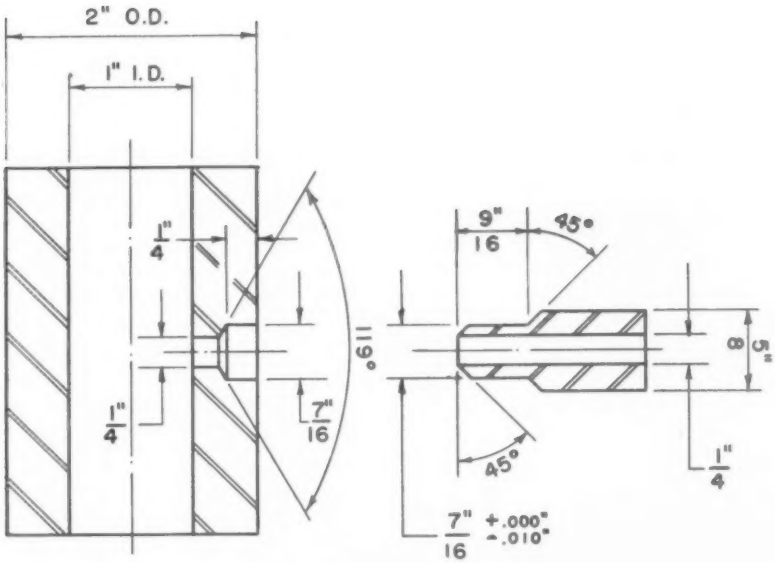

Fig. 5 Tee joint design

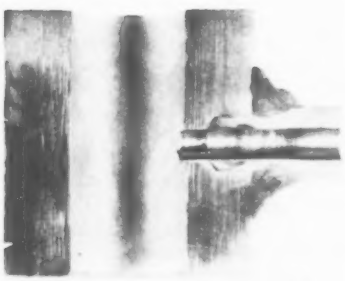

Fig. 6 Tee joint macrograph

it is intended for steady state operation, the presence of the potential stress raiser was disregarded. The design facilitates accurate assembling without the use of other than the simple positioning jig shown in Fig. 7.

SOCKET JOINTS

The details of the joint used to seal the bottom of the specimen tubes are shown in Fig. 8. This is a conventional socket joint. The plugs used in these joints were machined for a close fit.

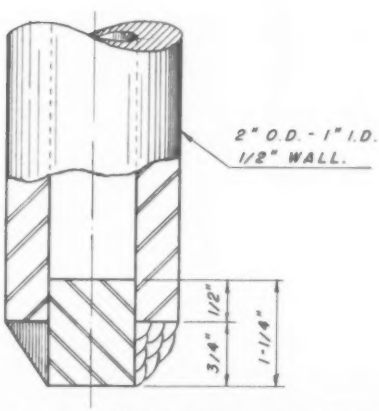

Fig. 8 Socket joint at bottom of specimen tube

DESIGN OF THE HEAT EXCHANGERS

The three counterflow heat exchangers of the installation are identical in design and are made of AISI 316 tubing. Each heat exchanger consists of two single-turn coils connected in parallel, as shown in the photograph of a scale model in Fig. 9. Each coil consists of a 0.750 in. OD, 0.187-in. wall thickness inner tube and a 2.00-in. OD, 0.500-in. wall thickness outer tube. The returning high-temperature steam will be passed through the inner tube and the incoming steam whose temperature is to be raised will flow within the annular space between the outer surface of the inner tube and the bore of the outer tube. The designs of the joint

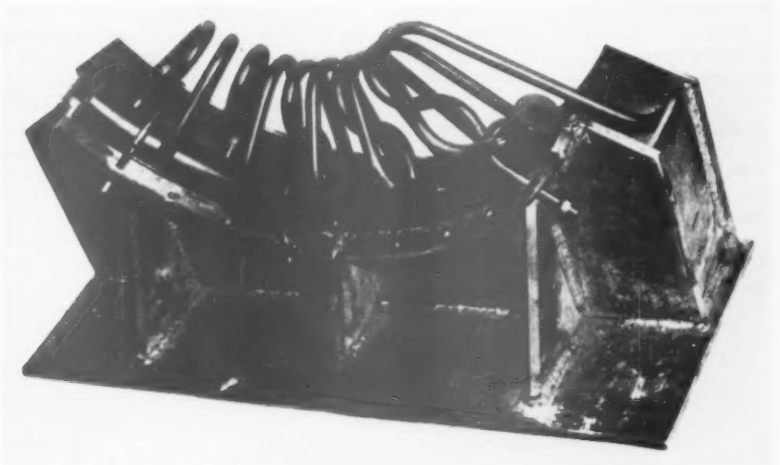

Fig. 7 Positioning fixture for welding header assemblies

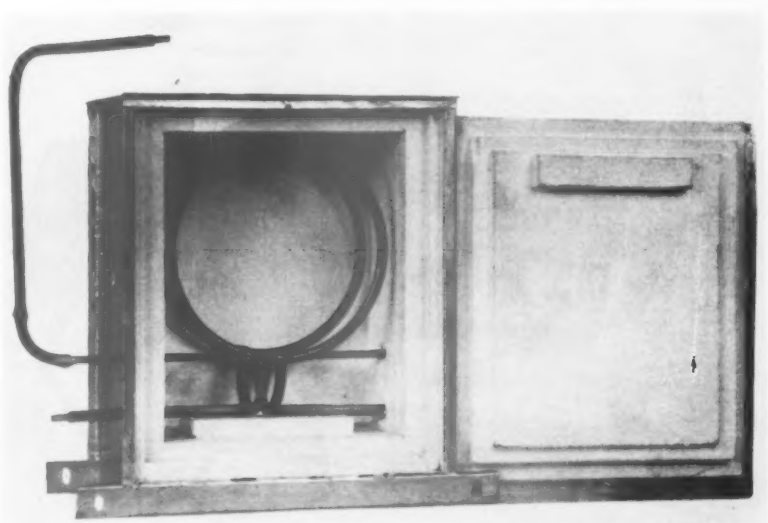

Fig. 9 Model of the heat exchanger

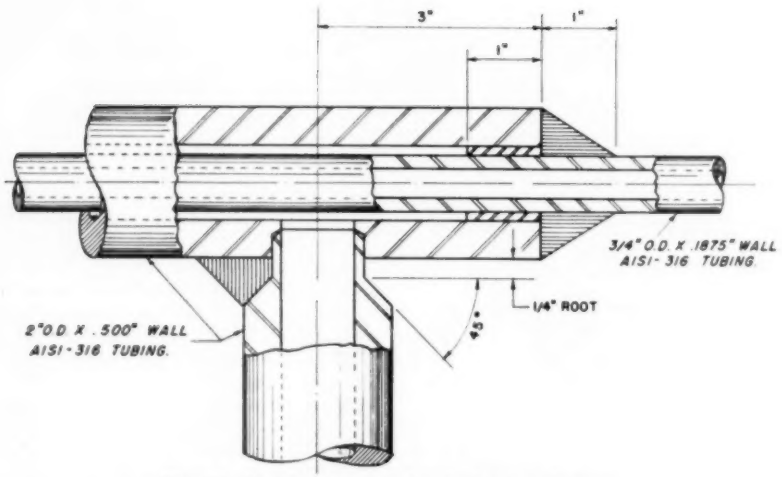

Fig. 10 Welded joint design in heat exchanger

which seals the space between the two tubes and of the saddle joint which unites the tubes to a common header are shown in Fig. 10. These heat exchangers will be installed within a suitable steel structure which will support the thermal insulation.

DESIGN OF THE SUPERHEATERS

The five superheaters will be of identical design and made of AISI 316 alloy tubing also. Figure 11 is a photograph of a scale model. Each of these superheaters will consist of a two-turn helix. The ends of the helix will be connected to one leg of a single-phase transformer whose other leg will be connected to the center of the helix. Thus, the flow of the current will be confined to the helix because the two end connections will be of the same polarity relative to the center connection. This design minimizes inductive losses. The lengths of tubing between the center and the end connections will be the resistance load in the circuit and, therefore, will serve to convert electrical energy into heat. The heat generated in the tubes will be transferred to the steam passing through these coils. The joints uniting the heavy terminal lugs to the superheater coil are shown in Fig. 12. There are no welded joints in the superheater tubing other than those which connect it into the line. These, as all the other butt joints, with the exception of the final tie-in connections will be of the ceramic-backing design.

The superheater coils will be encased in thermal insulation which will be supported by a steel frame.

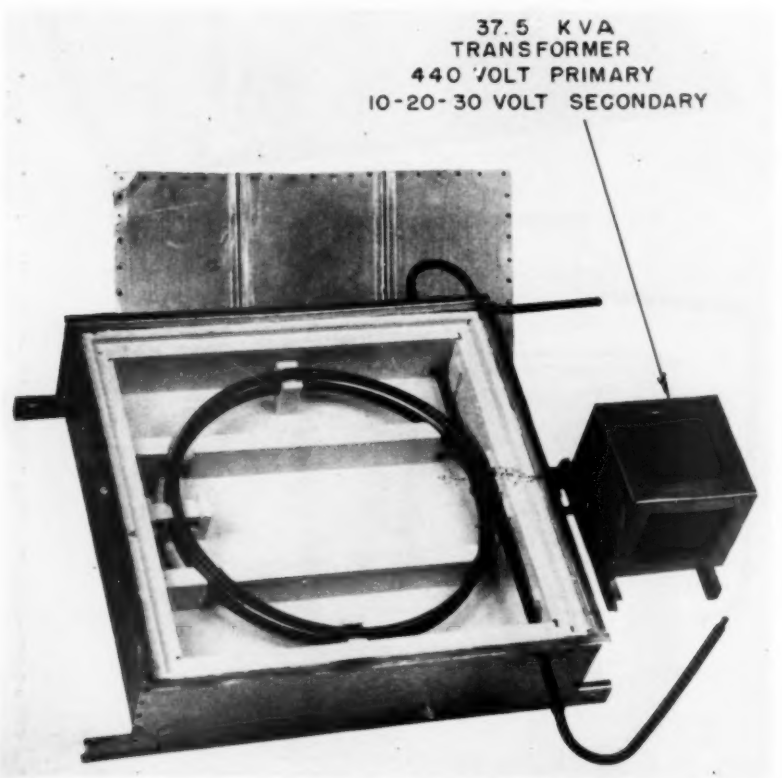

Fig. 11 Model of the superheater

WELDING PROCEDURES

All fabrication will be by metal arc welding using lime-coated electrodes throughout. The details of the procedures for the various alloys are given in Table 3.

INSPECTION PROCEDURES

Specimen tubes were inspected by chemical analysis to verify their composition. For soundness as to the presence of seams or cracks, they were inspected by a Borescope internally and by the penetrant method externally. For uniformity of hardness and composition throughout their length, the ferritic tubes were inspected using the Magnetic Analysis method. All electrodes will be inspected as to usability, and the composition of the weld metal deposited from these will be ascertained. Prior to welding the superheater racks, sample joints will be fabricated by all operators assigned to this work. The samples prepared by them will be X-rayed and dissected for metallographic examination. Only those operators will be permitted to fabricate joints of the superheater racks who qualify by the above examination. In course of production, X-raying will be impracticable. Inspection will, therefore, consist of examination of each completed pass using an illuminated magnifier to ascertain whether cracks, particularly crater cracks, exist. In the event cracks are noted, the weld will be permitted to cool to 150° F and then examined by the penetrant method. Each completed assembly will be tested hydrostatically at 3000 psi. Composite joints will be preheated differentially, i.e., the preheat temperature of the austenitic member whose coefficient of expansion is greater than that of the ferritic tube will be at a level below that of the ferritic member of the joint. The temperature difference of the two members will represent the inverse ratio of their coefficient of expansion. The composite joints will not be postheat treated. Photomicrographs representing the root area of a composite joint (ferritic and austenitic) are shown in Fig. 13 and Fig. 14.

Table 3

*Base metal**	*Electrode composition*	*Preheat, ° F*	*Postheat, ° F*
SA213T22	1.75–2.25% Cr, 0.5–1.0% Mo	400–600	1325 for 2 hr
SA213T21	2.25–3.0% Cr, 1% Mo	400–600	1325 for 2 hr
SA213T5	4.0–6.0% Cr, 0.5% Mo	400–600	1325 for 2 hr; 900 for 2 hr
SA213T16	4.0–6.0% Cr, 0.5% Mo	400–600	1325 for 2 hr; 900 for 2 hr
SA213T13	4.0–6.0% Cr, 0.5% Mo	400–600	1325 for 2 hr; 900 for 2 hr
SA213T9	9.0% Cr, 1.5% Mo	400–600	1325 for 2 hr; 900 for 2 hr
GE Cr Mo Va	0.55% Cr, 1.15% Mo, 0.15% Va	400–600	1325 for 2 hr
AISI 347 vs. SA213 T22	19% Cr, 9% Ni, 0.8–1.0% Cb	Differential	None
AISI			
304	19% Cr, 9% Ni	None	None
347	19% Cr, 9% Ni, 0.8–1.0% Cb	None	None
321	19% Cr, 9% Ni, 0.5% Ti	None	None
316	18% Cr, 13% Ni, 2.5% Mo	None	None
310	25% Cr, 20% Ni	None	None
309	23% Cr, 13% Ni	None	None
Armco 17–14 Cu-Mo	19% Cr, 14% Ni, 3% Mo	None	None
Timken 16-25-6	25% Cr, 20% Ni, 2% Mo	None	None
Inconel	15% Cr, 70% Ni	None	None
Incoloy	20% Cr, 35% Ni	None	None

* For compositions refer to Table 1.

NOTE: (*a*) Interpass temperature will be the same as the preheat temperature. (*b*) Composite joints will be preheated but not stress relieved. (*c*) Interpass temperatures where no preheat is indicated will be 200° F max.

INSTRUMENTATION

Control of the temperature levels throughout the entire installation will be automatically regulated. Temperature of the inlet and outlet steam for the specimen racks will be recorded. The recording instruments will be equipped with alarm devices which will shut off the electrical and steam systems in the event the temperature of any of the components falls below or exceeds the normal range of the permissible variations. All temperature control and indicating instruments will be actuated by thermocouples. The soot blowing operation will be controlled by an automatic timer coupled to solenoid values. In the event of a tube failure, provision is made for automatic shutdown of steam flow.

PROTOTYPE INSTALLATION

Once installed at the Philip Sporn Power Plant, it is desired that at each of the five specimen racks, the specified temperature level shall be maintained constantly and automatically, requiring only, occasional inspection and minimum attendance. To assure that all components of the proposed installation are capable of performing their specified functions, it has been found advisable first, to construct a prototype for evaluation of the various components. The prototype installation will consist of Specimen Rack No. 2 which will operate at 1200° F, one superheater, one heat exchanger and a desuperheater. All of these will be equipped with the instrumentation intended for the final installation. This prototype equipment will be set up at the U. S. Naval Engineering Experiment Station, Annapolis, Md., and operated for a sufficient length of time to evaluate the suitability of all components for the intended three year service. Should the above test indicate the need to modify the design of any of the component parts or the method of instrumentation, they will be modified at the U. S. Naval Engineering Experiment Station. Any such modification will be evaluated. Fabrication of the entire assembly will be started only after the committee has approved the prototype installation.

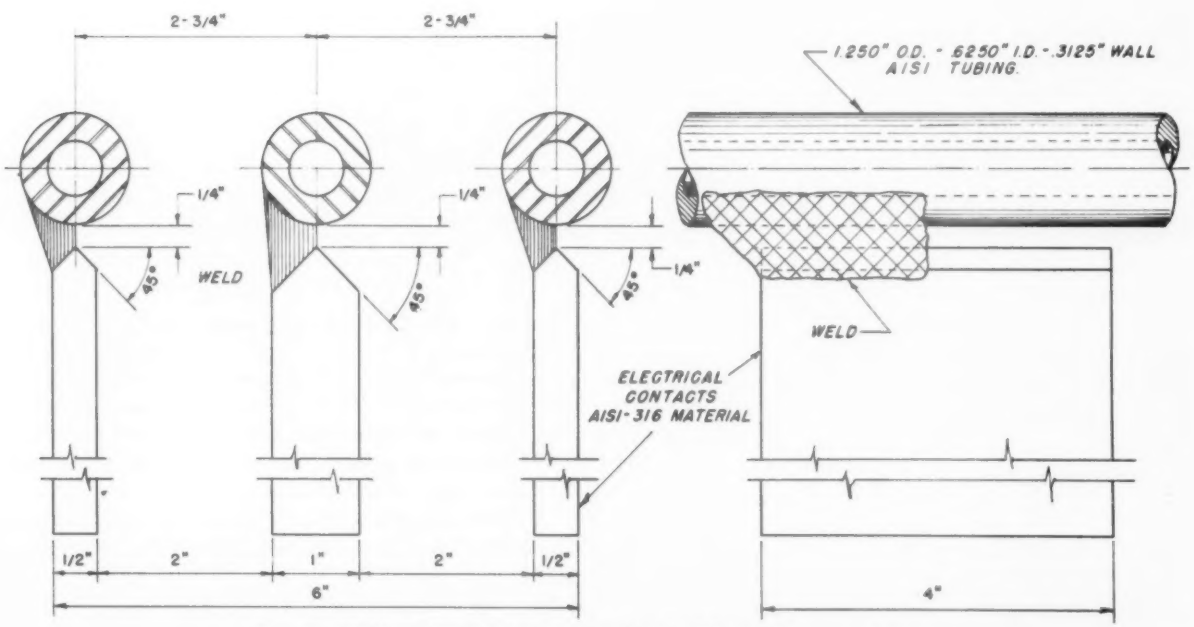

Fig. 12 Welded joint design for the electrical lugs of the superheater

Fig. 13 Root of composite joint, ferritic side. Photomicrograph × 100

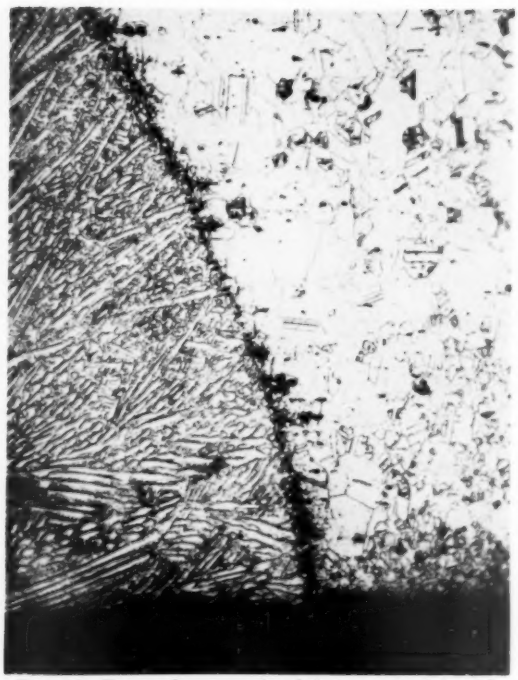

Fig. 14 Root of composite joint, austenitic side. Photomicrograph × 100

ACKNOWLEDGMENT

The authors express their appreciation for the information and design data furnished by George W. Kessler, Babcock and Wilcox Co.; for the advice and encouragement given by Prof. H. L. Solberg of Purdue University; the arduous work of George Lien, Senior Engineer, American Gas & Electric Service Corporation, who is in charge of procurement of materials and equipment; and for the constructive criticism and advice of the Fabrication Sub-Committee.

Peening Investigations

An interpretive report by the Peening Committee, Welding Research Council, based upon two reports issued by the American Bureau of Shipping Laboratory and a report issued by the Naval Research Laboratory

INTRODUCTION

PEENING* has been used by the welding industry for more than 35 years, but the code requirements and regulations governing this procedure have been based on opinion rather than on scientific data, for the very simple reason that heretofore there have been no means of measuring the effect of peening. Because peening is almost a necessary procedure in the welding of very heavy or restrained sections, industry requested the Welding Research Council to carry out a comprehensive investigation which would result in the evaluation of each of the variables, at least the most important ones, and their possible control in standardized procedures, codes or specifications.

Various specifications and codes have in the past generally required the following with regard to peening:

1. The first layer shall not be peened.
2. The last layer shall not be peened.

* The peening investigated by the Peening Committee of the Welding Research Council and the peening referred to in this interpretive report is the working of the deposited weld metal by means of an air hammer. It does not refer to shot peening as practiced in the automotive and other industries for the purpose of improving the fatigue strength of certain parts. Members of the Committee are: L. C. Bibber, *Chairman;* D. P. Brown, W. B. Bunn, C. E. Jackson, G. W. Place, R. D. Stout and W. Spraragen, Secretary.

Specifications also contain such phrases as "thoroughly peened" or "the work shall not be overpeened." Such requirements in specifications were largely based on judgment and experience. There was no quantitative information with regard to peening. Furthermore, nobody knew just how much peening should be done and nobody knew whether or not a weld was overpeened or what overpeening was. The first requirement, that the first layer should not be peened, had a firm foundation; namely, that peening of the first layer could actually pierce the weld or could displace the member sidewise. Peening of the last layer was prohibited largely on the general belief that cold working would injure the weld metal. However, in very severely locked-up welds peening had to be done or the welds would crack, and peening was a very expensive operation, in fact sometimes more expensive than the welding itself.

This situation existed when the committee on peening was formed. For several years this committee was at a loss as to just what steps should be taken and just who would take them. At least four universities and research agencies were given the problem of conducting peening tests and all of them threw up their hands and declined the job after a brief period of study. Finally the American Bureau of Shipping designed and had built a special welding and peening machine. It made possible the control of the fundamental variables of peening, such as speed of travel, energy in the blow of the hammer, determination of the riding load, etc.

The question of how to measure the effects of peening was studied very carefully. After several false starts, it was finally decided that inasmuch as the peening tool beat a groove into the plate or the weld, this groove could serve as the notch in a notched-bar specimen. Accordingly, it was decided that the various effects of peening could be measured by making transition temperature determinations of these notched specimens in which the base of the notch had felt the full effect of the peening. This was done and proved immediately successful. The various tests conducted by the American Bureau of Shipping include measurement of the effect of speed of peening, effect of peening at various temperatures, effect of postheat, effect of multipass peening and many other variables. This plan resulted in peening of the welds more severely than peening normally used in service.

CODE REQUIREMENTS

Inasmuch as the subject of peening had not been scientifically studied, the API-ASME Code for Unfired Pressure Vessels prescribes a method for checking the effectiveness of a peening procedure in an actual welding operation. According to this code, punch marks should be made on opposite sides of the weld; the distance between these marks should be kept within $\pm 1/32$ in. by peening during the welding of the seam, the first measurement being made after two layers of weld metal have been deposited. If the peening has been executed so as to hold the deviation in distance between punch marks to a minimum until the weld has been built to a depth of $1 1/4$ to $1 1/2$ in., the same degree of peening may be applied safely to the remainder of the weld.

As indicated in the Introduction, some codes prohibit the use of peening on the first layer and also on the last layer. These rules were based largely upon practical experience. The results of laboratory tests conducted by the American Bureau of Shipping and explosion bulge tests by the Naval Research Laboratory actually confirmed this practical experience.

SOME OF THE CONCLUSIONS BASED UPON LABORATORY TESTS

The following are some of the pertinent conclusions taken from the laboratory reports:

1. Calibration of the pneumatic peening hammers indicated that their frequency in blows per minute increased with higher air pressures but was not appreciably affected by the riding load. The energy per blow generally tended to increase somewhat with higher air pressures and with heavier riding loads.

2. Tests on prime plating showed that the impact properties were adversely affected by peening. The greatest loss in notch toughness occurred when peening was carried out in the range of 500 to 900° F and this effect is believed to be associated with working the metal in the blue brittle temperature range.

3. The notch toughness of prime plating peened at 10° F approached that obtained on unpeened material.

4. Tests on deposited E6010 weld metal showed that peening of the last weld layer resulted in a pronounced loss in notch toughness (a rise in the transition temperatures of 55 to 300° F depending on the conditions of peening). As in the case of prime plating, this effect was most pronounced when weld metal was peened in the blue brittle temperature range and when the peening was more drastic.

5. The low-hydrogen E6016 weld had much better notch toughness in both the unpeened condition and as-peened at 70° F than the E6010 weld in corresponding conditions (a drop in the transition temperature of 90° F in each case).

6. The submerged arc weld compared favorably in notch toughness with the E6010 weld in both the unpeened condition and as-peened at 70° F.

7. No attempt was made to determine the range of variations expected for any class of electrode or submerged-arc welding composition. Although only typical commercial materials were used, it is felt that other materials would not modify the general conclusions regarding the effect of peening.

8. A stress-relieving treatment at 1150° F partly eliminated the adverse effects of mild peening on an E6010 weld but it had very little effect when the peening was more drastic.

9. The adverse effects of peening an E6010 weld layer were eliminated by a subsequent covering weld deposit.

10. The peening of prime plating or weld metal resulted in a pronounced increase in hardness and this increase was more severe when peening was carried out in the blue brittle temperature range.

11. Peening of the last layer of weld metal should be considered a dangerous practice which greatly increases the hazard of the initiation of brittle fractures.

RECOMMENDATIONS OF THE COMMITTEE

As a result of this research work, the Committee recommends certain precautions and suggestions to code-writing bodies and engineers and others in charge of the responsibility of controlling peening operations. These are divided under two headings, precautions and suggestions.

Precautions. There is ample evidence to reaffirm existing code requirements prohibiting the use of peening on the first and last layers. Such prohibition is necessary even though a structure or weldment may be stress relieved after the peening. Existing code rules controlling distortion with the aid of bench marks seem entirely adequate. Although the tests indicated extreme loss of notch toughness when peening is carried out in the range of 500 to 900° F, the effect is removed by a subsequent weld deposit, providing no deep or extensive cracks resulted from the peening operation in this blue brittle range.

Suggestions. One of the uses of peening is to control distortion. Each succeeding pass of peening can bring about further dimensional changes. Most of the dimensional changes occur very locally. It is necessary to study carefully the dimensional changes as some portions of the weldment can be put in compression and others in tension. The amount of dimensional changes is greatest at the center of a peening length and smallest toward the ends. Other tests not conducted by the Committee, but which have been reported in the literature, indicate that whereas peening may distribute residual stresses, it cannot be counted upon as a stress-relieving operation unless the last pass is peened, which, of course, should be prohibited because of the resultant loss in notch toughness. Peening has been found desirable in the welding of heavy restrained sections. Usually the peening is done while hot to prevent cracking upon subsequent cooling. The damage caused by the working, providing no deep or extensive cracks resulted from the peening operation, is removed by subsequent weld layers. While peening is effective in removing buckles, thin material should be supported during peening operations as excessive peening may itself cause buckles. In holding a pneumatic peening tool, excessive down pressure is tiresome and may actually interfere with the smooth operation of a peening tool. It is not particularly effective in increasing the amount of peening. Sufficient pressure should be used to prevent the tool from jumping around.

Although all of the test results have been made on mild steel, there is every reason to believe that they would be equally applicable to low-alloy steels, assuming, of course, that no deep or extensive cracks resulted from the peening operation

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Relief of Internal Stresses at 400–575° F

Abstract of "Dans quelle mesure la relaxation des tensions se produit-elle à 200–300° C," written by R. Gunnert and published in *Rev soudure*, **9** (4), 195–206 (1953). (Abstracted by Dr. G. E. Claussen.)

At the Oxford meeting of the International Institute of Welding in 1951 there was considerable discussion of the substitution of a treatment at 400–575° F, by superheated steam, for example, for the usual stress relief heat treatment at 1200° F. The efficacy of the treatment at 400–575° F was determined under uniaxial and biaxial stress. The uniaxial tests employed a relaxation specimen of mild steel bolted in a restraining frame. In the biaxial tests a thick butt-welded plate was used. The plate was $1^1/_4$ in. thick, and was welded in 36 passes, the weld being allowed to cool after each pass. The stress in the weld was determined by a special extensometer (0.35-in. gage length) and rosettes on the surface of the weld.

The maximum stress remaining in the uniaxial tension bar after treatment up to 575° F was equal to the yield point of the steel at the temperature of treatment. Likewise in the biaxial tests the maximum internal stress at the surface of the weld was equal to the yield point of the weld metal at the temperature of treatment. In both instances the maximum internal stress after treatment at 575° F was 70% of the yield point of the material at room temperature.

Brittleness Tests

Report No. SR532/2 of the Netherlands Welding Research Center compares notch-impact and static bend tests to evaluate the transition temperature of one killed and two rimmed steels in and across the direction of rolling. The work was done in cooperation with the Belgian Mixed Commission on Steels. The notch-impact specimens were $^3/_8$ in. square, $2^3/_{16}$ in. long with five different notches: Charpy keyhole, Charpy V (Izod) and three Schnadt types. The static-bend specimens were of three types: Kommerell, Soete and Van der Veen, the last having been described in the January 1953 issue of the *Journal of the Iron and Steel Institute.*

The report concludes that the static bend test is preferable to an impact test, because the former utilizes a static load, which corresponds with service, and the full plate thickness is involved in the test. Of the three static tests, the Van der Veen is preferred because both ductility and fracture transitions are determined, the notch is similar to those occurring in practice and the test can be performed easily and accurately. Of the notch impact specimens, the Charpy V notch is preferred. The report is published in *Lastechniek*, December 1953, pages 247–264.

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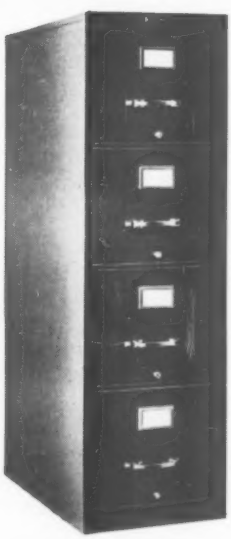

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